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FINAL PROJECT REPORT

TERMINAL 91 SHORT FILL MONITORING PROGRAM

Prepared for

Port of Seattle

by

Converse Consultants NW

in association with

Pacific Groundwater Group
Hall & Associates

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SECTION I

TERMINAL 91 SHORT FILL PROJECT EXECUTIVE SUMMARY

Description and Background of the Project

In 1985, the Port of Seattle began construction on a pioneering effort which would combine pier expansion with the safe use of contaminated dredge materials. The innovative and successful effort was conducted under the watchful eye of regional environmental regulatory agencies.

Today, the Terminal 91 Short Fill Project is a functioning and economical 'near shore' confined disposal facility which not only effectively contains contaminated materials beneath a busy cargo terminal, but provides a model approach and background knowledge for other sites. The Terminal 91 project is believed to be the first facility of its kind in the United States.

Careful monitoring during construction and for five years following completion has shown that a near shore confined disposal project can be designed and built to safely prevent contaminants from entering surrounding waters.

The Terminal 91 Short Fill Project came about because the Port of Seattle needed a disposal site for materials from several planned in-water construction projects and from routine maintenance dredging.

Dredging is essential for any prosperous and growing port. Shipping channels, pier slips, expanded docks and other facilities require dredging. Over the past ten years, the Port of Seattle has had to remove and dispose of more than a million tons of dredge material.

Dredging is very expensive. In the past, dredge materials were shipped to open water disposal sites but environmental concerns and new regulations placed on in-water disposal methods strictly limited its use by the mid-1980's. Removal of contaminated dredge materials to an upland landfill or confined disposal site became the remaining but more costly alternative.

In 1984, the Port contracted with Nissan to expand the terminal at the existing Piers 90 and 91. The terminal would be used for unloading and temporary storage of automobiles. Piers 90 and 91 extended parallel to each other from the northern shore, south into Elliott Bay. To expand the terminal and build the new facility, the Port planned to fill the northern area of the slip between the existing piers. This *Short Fill* would connect the piers and provide the space needed by Nissan, with room for future expansion if necessary.

The construction of the new terminal required a large amount of fill. Port officials realized that the project could also serve as a disposal site for moderately contaminated dredge materials from other projects. However, the facility would have to contain the contamination, avoiding any pollution of the 90/91 slip and Elliott Bay.

A thorough feasibility study was completed to assess the circumstances and to determine the best design to both contain the contamination and meet the project's construction requirements. Research consisted of a series of geochemical, hydrogeological and geotechnical studies to select the best short-fill design. The goal was to find a design that would protect the environment, allow for timely and cost-effective construction and not interfere with the aging Magnolia Viaduct.

Before work could begin, the Washington Department of Ecology required a consent agreement with a contingency plan outlining the responses the Port would make if unacceptable contamination occurred. This agreement, reached after extensive negotiation, has helped set standards for other near shore confined disposal projects in the Northwest and is formally recognized by the U.S. EPA and the U.S. Army Corps of Engineers as the performance document for this project.

The design study and permit negotiations were completed and construction of the Short Fill began in mid-1986. The project consisted of two long *berms* -- mounds of clean, structural fill -- extending across the 90/91 slip to link the two piers. The berms were explicitly designed to contain the contaminated sediments which would be placed between the berms, and Piers 90 and 91. Each berm contained clean fill with sandy gravel cores, covered with *rip rap*, or large rocks which would withstand pounding waves. The contaminated dredge materials were then placed between the berms. After a six month construction delay, the water was pumped off and the fill was completed with uncontaminated sand and gravel and paved with asphalt. A stormwater drainage system was installed to safely handle rainwater and runoff and a system of monitoring wells was installed as part of the Short Fill design to adequately collect data and analyze how the facility would perform over time.

Computer Modeling Studies

During the feasibility study, computer modeling studies were undertaken to look at the possibility of long-term movement of contaminants from the project and to assure that the design functioned as planned.

An initial study relied on a simplified steady state model. This early model could not accommodate tidal action at the site and showed that a more complex analysis would be required.

A more sophisticated model was developed which could better assess tidal effects and at the same time predict contaminant transport, flow and mixing within the berms. This second model predicted that the Short Fill design would adequately contain the contaminants. Regulatory agencies consented and the Port proceeded with construction.

The model was later revised and validated after construction and monitoring using actual system dimensions and data collected about groundwater flow, containment levels and transport.

The computer model provides conservative but reasonable estimations, rather than precise predictions. Simplified assumptions in the model are conservative in nature and cause the model to predict concentrations that are greater than those actually measured.

Performance Criteria

To verify the prediction that the Short Fill system would contain contaminants as demonstrated in the model, and to develop a remedial action plan if it did not function as predicted, the Port prepared the Criteria, Threshold, Monitoring and Remedial Action Plan.

This plan established basic criteria and a monitoring program for measuring performance of the Short Fill. The plan:

- Set threshold levels for initiation of remedial actions;
- Established a remedial action agenda;
- Provided research and monitoring data that would also be applicable to other dredge disposal projects.

Performance criteria for the plan were established in cooperation with the lead regulatory agencies: the U.S. Army Corps of Engineers, U.S. EPA Region 10 and the Washington State Department of Ecology. The existing 1985 EPA chronic marine water quality criteria were used. For contaminants for which no EPA accepted criteria existed, the criterion used was ten times the level found in the background seawater in Elliott Bay.

According to the plan, any remedial action decisions which needed to be made would be based on sampling results from existing monitoring wells. Decisions would be made in a step-by-step manner. Measured levels in samples would have to be statistically greater than pre-determined threshold levels in order to elicit remedial action. This would require going back and resampling wells to statistically show that increased levels were a result of contamination. In addition, elevated levels would also have to be demonstrated to be from the contaminated dredged materials.

Threshold levels which would require action were defined as levels of contaminants in a south berm monitoring well that would indicate contaminants had reached to the face of the south berm. These levels would require remedial action.

Determination of any potential environmental impact from elevated levels at the berm face would rely upon the EPA list of "Lowest Reported Toxic Concentration" for contaminants shown to affect certain marine species.

Monitoring Activities and Results

Results from the computer modeling studies were used to determine locations and sampling depths of the monitoring wells. Well locations were chosen to best monitor the performance of the system in terms of hydraulic flow and contaminant concentrations.

Wells were placed in the berms, in the contaminated dredge fill, in the cap material and in areas near the Magnolia Bridge which would be in an upgradient groundwater flow direction from the Short Fill. The wells were positioned to monitor how groundwater flowed into, within and to the Short Fill.

The established performance criteria for contaminants of either the 1985 EPA chronic marine water quality criteria, or ten times background seawater, would be applied to the long term average, or chronic concentrations in the monitoring wells.

Throughout the monitoring period, sampling clearly showed the Short Fill had met and exceeded performance criteria.

While some levels for a few metals including nickel were elevated in the south berm wells, it was shown that these metals came from the clean structural fill in the berm itself and not from the contaminated dredge material. This was an important lesson learned from the project.

A follow-up modeling study was conducted in 1990 after the facility had been monitored for four years. This study updated the earlier model using actual as-built measurements, the current understanding of contaminant behavior and the measured monitoring results. Results from this later model predict that concentrations of contaminants at the berm face would be lower than was predicted by the first model. However, the percentage of the total amount of contaminants in the Short Fill which would be leached during the first 100 years of operation were predicted to be higher in than previously modeled, although generally less than one percent of the total. This higher percentage leached resulted primarily from greater estimated flow rates through the facility due to the way in which the facility was constructed.

Chronic saltwater bioassay tests were performed to research any biological effects the Short Fill might have on aquatic organisms. No adverse effects could be found. These tests provided supportive evidence that the facility is not a source of contamination and that it performs as designed.

In all, the monitoring demonstrates that the containment structure meets regulatory and environmental requirements outlined in the consent agreement between the Port of Seattle and the Department of Ecology.

Containment of organic and inorganic contaminants in the dredged materials was clearly shown to be working within the Short Fill facility. Overall confinement was shown to be related to the interrelationship between the hydraulics and the biogeochemistry within the facility as described below.

First, the low permeability of the dredged material limits the overall flow rate and transport of contaminants through the facility. Second, the saturated anoxic conditions within the dredged material limits the release of inorganic and organic contaminants from the dredged material and into the groundwater. Third, the highly permeable berm allows tidal action to constantly mix fresh, oxygenated seawater deep into the berm. This

fresh oxygenated seawater reacts with any reduced inorganic or organic contaminants which are being slowly released from the dredge material at very near the berm-dredged material interface. This results in the precipitation and immobilization of the inorganic contaminants along with some of the organic contaminants along with the enhanced aerobic biodegradation of any organic contaminants deep within the berm. Fourth, any remaining contaminants not fully immobilized or degraded in the inner portions of the berm will be significantly diluted in the outer portion of the berm by tidal mixing and dispersion.

The biological and geochemical processes occurring within the berm, namely precipitation, immobilization, and biodegradation, are the same processes used in wastewater and contaminated groundwater treatment systems.

The Short Fill is environmentally protective. It will contain (confine) approximately 99 to 100 percent of contaminants of concern over a 100 year time frame. Of the minor percentage of contaminants released, it limits the levels to below action thresholds outlined in the plan agreed upon by the Port and the Department of Ecology. Data collected over the past five years indicate there are no detectable organic contaminants and only low levels of metals within the berm which are from the berm itself. Low level contaminants in the berm have concentrations below saltwater standards and are well below ten times the sampled background stations.

Continued Monitoring

Due to environmental concerns and regulatory interest, some level of continued monitoring may be appropriate at the Terminal 91 Short Fill. As the monitoring data has shown, the facility has generally reached a geochemical stasis condition over the past five years. Therefore, a reduced level of monitoring is recommended as average concentration levels are expected to change very little over the next few decades. These monitoring activities should, however, follow the slow advance of the fresh groundwater through the facility, and increase in frequency as the freshwater approaches the outer berm.

Much of the information gathered to date has helped to better understand the processes of operating a near shore confined disposal facility. Monitoring in the berm at short intervals, varying with the tide, is extremely effective. It is also very important to distinguish suspended from dissolved contaminants in the monitoring wells.

Scaling to Smaller or Larger Projects

Larger near shore confined disposal facilities with longer berms and greater amounts of contaminated dredged material are likely to release proportionally higher total amounts of contaminants over time, but not necessarily greater concentrations or a greater percentage loss of contaminants from the system. If performance standards are based on concentration or percent confined, then a larger facility may be acceptable.

If a very large facility with a long berm were constructed in a relatively pristine area, with background levels of contaminants and no other sources of contamination, and with poor circulation and flushing, then the low percentage loss may possibly show detectable accumulations near the facility. In this situation, if performance criteria are based on comparisons between contaminant levels near the facility and pristine background levels, a more conservative design may be considered.

Smaller facilities with narrower berm cross sections may have reduced mixing and dispersion within the berm and therefore may discharge higher concentrations. If standards are based on concentration, a smaller berm may not be acceptable. However, the total amount of contamination reaching the receiving water over time may be less in a smaller facility. Thus, if performance criteria are based on comparison with background levels near the facility, the lower discharge volumes may not cause unacceptable concentrations closer to the berms.

Important Design Guidelines

Three design factors were found to be most important to increase the environmental protection of the Terminal 91 containment facility:

- Lower permeability for the dredge fill and higher permeability for the berm;
- A low groundwater gradient through the facility to limit flow through the system;
- Low permeability sediments throughout the entire saturated area above the fill.

It has been shown that the asphalt top layer plays a dual role. In addition to providing storage for vehicles, it channels precipitation to the stormwater drainage system before it can infiltrate into the fill.

Conclusion

The Terminal 91 Short Fill Project has fulfilled its original purposes, providing design success and insight into the mechanisms of contaminant containment, as well as information that can be applied to other sites.

SECTION II

INTRODUCTION

The Terminal 91 Short Fill is a contaminated dredged material fill designed and constructed by the Port of Seattle. The Short Fill was constructed in a hydraulically active near-shore tidally-influenced environment by partially filling an existing slip between Piers 90 and 91 in Elliott Bay. The contaminated dredged material was placed behind clean fill berms with no special liners or leachate control system. The design assumes that most of the contaminants would remain associated with the particulates and would be controlled by physical containment and by maintaining the general sedimentary and geochemical conditions of the dredged materials.

The Terminal 91 Short Fill Monitoring Program was developed by the Port of Seattle in cooperation with state and federal agencies. The scope of the program actually goes beyond strictly monitoring and was designed to predict, monitor, and potentially remedy the containment performance of the Short Fill based on pre-established performance criteria. The purpose of this report is to organize and bring together the major studies and results and of the Terminal 91 Short Fill Monitoring Program, to evaluate the success of the project in terms of the performance criteria, and to summarize the lessons learned which could be applied to future similar projects.

The report is organized chronologically beginning with Section III which describes the physical setting and project background. Section IV discusses the project planning portion of the project including modeling predictions of the Short Fill performance. Section V, Project Permitting, presents the Criteria, Thresholds, Monitoring and Remedial Action Plan which was developed by the Port in cooperation with the Washington State Department of Ecology. It is the formalized agreement between the Port and the agencies which establishes the performance criteria, monitoring plan, and remedial action plan for the Short Fill and is part of the dredge and fill permit for the project. Section VI describes the Short Fill construction and monitoring well installation projects. Section VII outlines the details of the planned and implemented monitoring program for the Short Fill. It presents the monitoring activities, schedule, and sampling location description. Section VIII, presents the results of the monitoring program. The focus of this section is on the comparison of the results with the performance criteria and includes a discussion of the modeling follow-up study which was conducted using the monitoring results. Section IX gives an overall evaluation of the success of the system based on the performance criteria, and other biological testing conducted on the Short Fill. Section X outlines and discusses the major lessons learned and application of this information to the design and monitoring of future projects. Detailed backup information, explanations, and analyses are available in the referenced appendices.

SECTION III,

PROJECT BACKGROUND AND REGULATORY HISTORY

During the mid 1980's, dredging and disposal in Elliott Bay became increasingly difficult as Port representatives, regulatory agencies and others involved with dredging activities realized the inadequacies of the existing practices for testing and disposal of dredge materials containing industrial contamination. Increasing concern over the potential impacts of contaminated dredge material on the benthic environment lead to policy changes and guidelines which required more extensive bulk chemical testing of the dredge materials before in-water disposal would be allowed. Previously, tests were conducted on a case-by-case basis emphasizing short-term water quality effects during dredging and in-water disposal rather than affects on the benthic environment following disposal.

The first bulk chemical testing guidelines for Elliott Bay were established in 1984 for Fourmile Rock, which was the existing open-water disposal site in Elliott Bay. These guidelines were know as the Fourmile Rock Interim criteria and were developed in June of 1984 by Ecology and EPA. The Fourmile Rock criteria were based on best professional judgement at the time and were submitted to DNR as conditions on the shoreline master use permit issued by the City of Seattle to DNR to allow continued use of the disposal site on an interim basis while criteria for Puget Sound as a whole were being developed.

In August of 1984 the City of Seattle issued the permit to DNR for continued use of the site. The permit was immediately appealed to the Shorelines Hearings Board which closed the site until the appeal could be heard. In April 1985 the Shorelines Hearings Board decided against the appeal and the City of Seattle was then sued in Superior Court which kept the site closed by court order until June. The order was lifted in June of 1985, the law suit was not pursued, and the site was opened under the Fourmile Rock criteria.

In 1985 the Puget Sound Interim Criteria were also released by Ecology which covered all disposal in Puget Sound except the Fourmile Rock disposal sites. In 1988 the PSDDA Final Environmental Impact Statement was released and the new Phase I (Central Puget Sound) disposal sites in Elliott Bay and Port Gardner were opened in 1989 under PSDDA.

It was during this time period in 1984 that the Port of Seattle was seeking a disposal site for dredge materials from planned dredging projects at Terminals 30 and 105. The Port also needed a disposal site for their routine maintenance dredging. Under the existing chemical testing guidelines, some of the materials from these projects exceeded the criteria and were considered not suitable for open-water disposal at Fourmile Rock or other existing open-water disposal sites in Puget Sound. Without an acceptable open-water disposal site, the Port would be required to either delay construction while alternative contaminated disposal site regulations were developed, or use a much more costly option of disposal at an upland solid waste landfill.

Also in 1984 the Port contracted with Nissan, its major existing tenant at pier 90, to create additional terminal area for unloading and temporary storage of automobiles. This new area would be constructed between the existing piers 90 and 91 just south of the Magnolia Viaduct. As part of this new Terminal 91 construction, the Port planned to fill the northern section of the 90/91 slip between Piers 90 and 91. The connection between the piers was necessary to provide space for immediate offload parking of vehicles from ships offloading at either Pier 90 or 91.

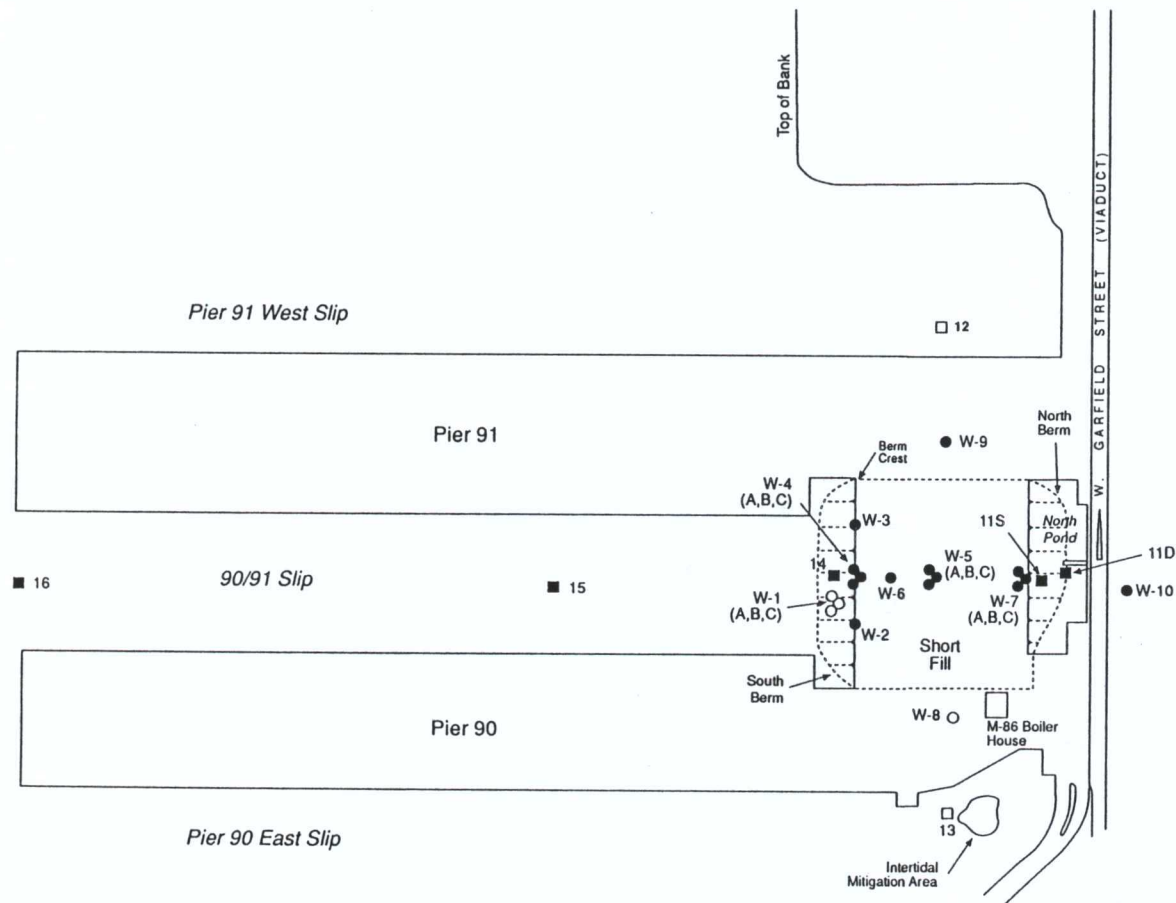
About 7.6 acres of intertidal land between the piers would be filled. In recognition of this partial or "short fill", this project became known as the "Terminal 91 Short Fill" (Figure 1). The Terminal 91 Short Fill (Short Fill) could be expanded in the future to provide more area, if needed, by filling the remaining slip between the piers.

At this point in time, the Port had two immediate needs:

- A large volume of fill to construct the Terminal 91 Short Fill; and
- An acceptable disposal site for the mildly contaminated dredge materials from the other dredging projects.

Port officials realized that both of these needs could be met by filling the slip at piers 90 and 91 with the mildly contaminated dredged materials. This in essence would provide a near-shore disposal site for the contaminated dredge materials. However, this could only be done if the facility contained the contamination so as to provide adequate environmental protection for the waters of the 90/91 slip and Elliott Bay. It was within this context that the Port proceeded with project planning for the Short Fill as discussed in the following section.

Elliott Bay



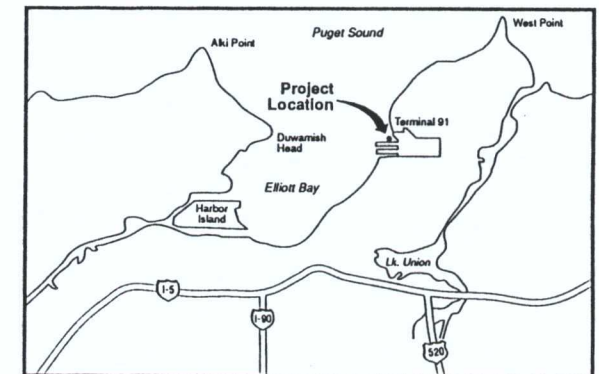
LEGEND

- Monitoring Well
- Proposed Monitoring Well
- Sampling Station
- Proposed Sampling Station

Scale



VICINITY MAP



MONITORING WELLS AND SAMPLING STATIONS

TERMINAL 91 SHORT FILL MONITORING PROGRAM
AMENDMENT #2 TO FINAL REPORT
Seattle, Washington
for The Port of Seattle

Project No.

90-35209-07

Figure No.



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SECTION IV

PROJECT PLANNING AND RELATED STUDIES

In 1984, when the Terminal 91 Short Fill was first proposed, the regulatory agencies believed that the Port lacked sufficient field data on long-term contaminant mobility from tidally-influenced near-shore disposal sites to fully evaluate the project. A series of meetings and discussions between the Port and the agencies ensued during which ideas and approaches to resolving the issue and filling data gaps were debated. Major agency input during these discussions came from EPA Region 10, the state Department of Ecology, and the U.S. Army Corps of Engineers.

The primary agency concerns which surfaced during these discussions were how to reasonably predict, monitor, and potentially remedy, to the agencies satisfaction, the performance of the disposal site. As a first step, the Port needed to assure the agencies that the containment system would provide adequate environmental protection based on existing water quality criteria. In order to evaluate the potential level of environmental protection the facility would provide, the agencies requested a reasonable prediction of the percent loss of the total amount of contaminants in the fill over time, and the potential impact on the water quality of the surrounding marine waters.

To evaluate the projected performance of the Short Fill, the Port proposed a modeling approach to predict the long-term contaminant mobility from the Short Fill. Two modeling studies were conducted to predict the performance of the Short Fill as a containment system for the contaminated dredged material fill:

- A simple analytical model, and
- A flow model coupled to a transport model using estimated data.

The first study used a simplified steady state model (URS, 1985) and could not accommodate the dynamic effects of tidal action, indicating that a more complex analysis would be needed.

A more sophisticated model was then developed (Hart Crowser/URS, 1985 and Appendix A.1). This model coupled flow and transport of contaminants. It was designed to better assess the effects of tidal action on contaminant transport and mixing within the berms. Estimated data were used in this effort as the facility had not been built. The estimates were based on published chemical analyses from similar yet fairly contaminated dredge materials from the Duwamish Waterway, and physical testing of materials similar to those expected to be used for the berms. Modeling assumptions used were consistently conservative in a direction which would produce worst-case results. The report from that study, the Phase I modeling report (Appendix A.1), predicted that the Short Fill design would provide acceptable containment and would not likely produce concentrations at the berm face which exceeded chronic saltwater criteria.

SECTION V

PROJECT PERMITTING

The favorable modeling predictions from the Phase I modeling report discussed in the previous section, were cautiously accepted by the regulatory agencies. The agencies would allow the Port to proceed with the Short Fill project with the agreement that the Port would also prepare a plan to monitor the system's performance and to potentially remediate the system if it failed the performance criteria agreed upon by the Port and the agencies. To verify that the Short Fill system would perform as predicted, and to have a plan to remediate the system if it did not, the Criteria, Threshold, Monitoring and Remedial Action Plan (CTMRAP or the Plan) was prepared by the Port, revised by Ecology, and signed by both parties. The Plan was submitted as part of the Water Quality Certification for the Terminal 30 Expansion Project 404 dredge and fill permit.

The Plan was the final requirement for the approval of the construction of the facility and was issued as a consent agreement between the Port of Seattle and Ecology. The agreement is basically a contingency plan outlining the various responses the Port would make if the monitoring results showed concentrations above threshold levels using an established water quality-based performance criteria. The CTMRAP agreement was also formally recognized by EPA and the Corps of Engineers as the performance document for the project.

The major purpose of the Plan was:

- To establish the basic criteria against which performance of the disposal site would be measured;
- To detail a monitoring program for measuring performance and tracking the movement of contaminants at the site;
- To set threshold levels for initiation of remedial actions;
- To establish remedial actions that would be implemented if the system did not meet the performance criteria and should prove to be a long-term water quality problem;
- To provide research and modeling verification that would make the results more applicable to other dredged material disposal projects; and
- To establish a monitoring plan to insure the protection of local water quality during the filling operation.

The following subsections describe the major elements of the Plan including the performance criteria, action thresholds, the remedial action plan and the monitoring program.

V.1 PERFORMANCE CRITERIA

The performance criteria were established in cooperation with the lead regulatory agencies: the Army Corps of Engineers, EPA Region 10, and the Washington State Department of Ecology. The existing 1985 EPA chronic marine water quality criteria were used as a starting point. For those contaminants which had no EPA accepted criteria at the time, ten times background seawater concentration was established as the criterion. The background seawater values would be determined from samples collected in the 90/91 slip between Piers 90 and 91. Initially, five replicate samples were collected in May, 1985 to establish the mean and standard deviation of the background concentration. These values would be updated with the inclusion of the data from the monitoring program.

The discharge from the fill during consolidation and dewatering (first six months) was considered part of construction phase of the project. During this phase the discharge was categorized as an acceptable short-term impact within the dilution zone as established in the Water Quality Certification. However, the discharge would have to meet the EPA acute marine water quality criteria within the dilution zone. The dilution zone extended 100 meters south of the south crest of the south berm.

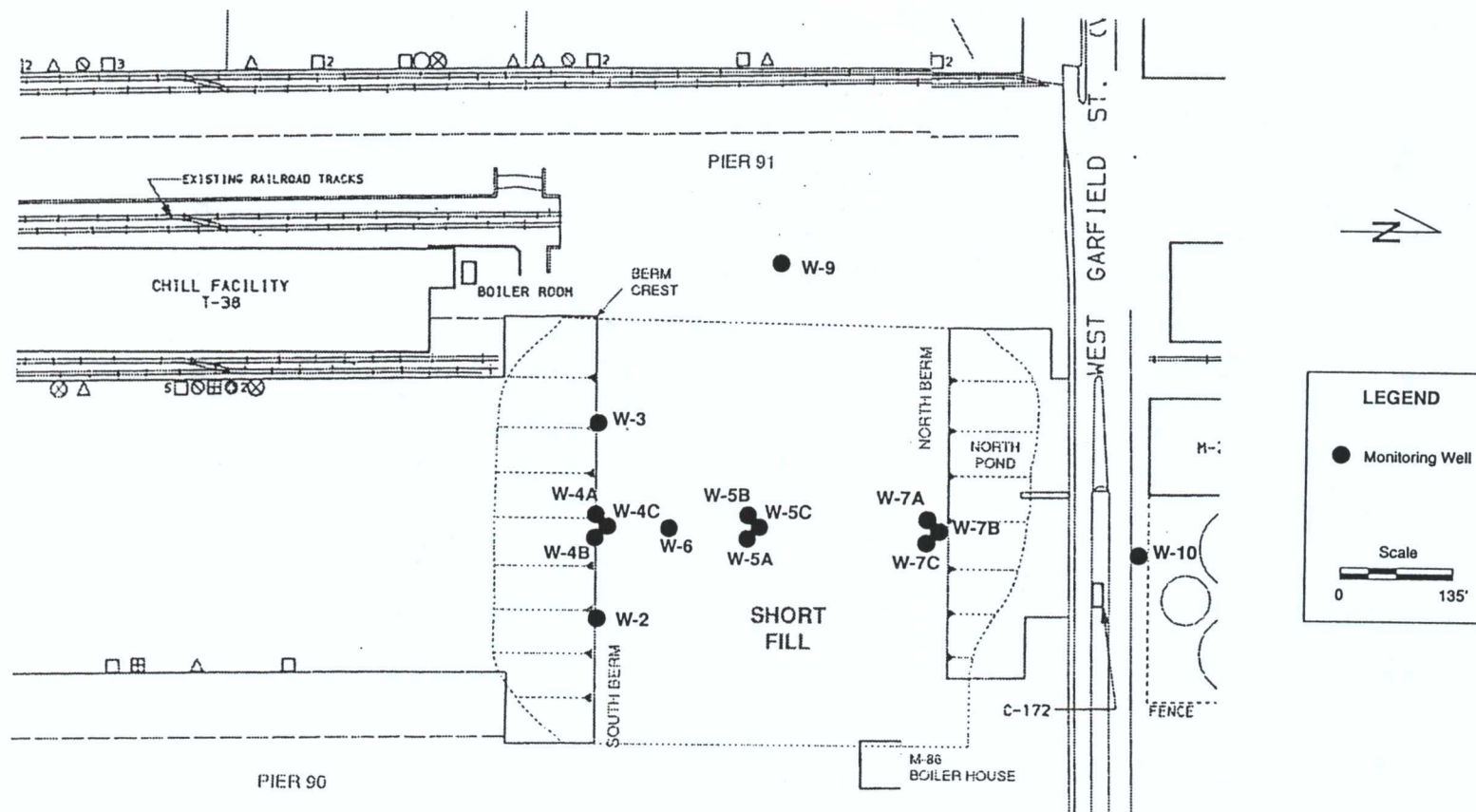
The post-construction point of compliance for chronic criteria was considered to be the long-term average (i.e. chronic) concentration at the berm face through which the major discharge was predicted. The most probable pathway and therefore the major point of compliance established was the south berm face in the slip between Piers 90 and 91 (see Figure 2).

V.2 ACTION THRESHOLDS

The action threshold levels are defined in the Plan as those levels in the monitoring wells that would indicate a high probability of exceeding chronic saltwater criteria at the south berm face. Exceeding the action threshold would indicate a failure of the disposal site to adequately contain the contaminants. Exceeding the threshold values would justify initiating remedial action to contain the contaminants.

Two tiers of threshold levels were established:

1. Above the saltwater background values, and
2. Above EPA chronic marine water quality criteria or above ten times the saltwater background value.



MONITORING WELL LOCATIONS

TERMINAL 91 SHORT FILL MONITORING—FINAL REPORT
 Seattle, Washington
 for The Port of Seattle

Project No.
 90-35209-03
 Figure No.



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 and Applied Earth Sciences

Exceeding either of the threshold levels would initiate notification of Ecology, EPA, and the Corps. The agencies would confer with the Port to determine:

- The potential environmental impact;
- The possible need for three additional confirming samples;
- If necessary, the appropriate dilution factors to be applied to the values determined from the wells; and
- The appropriate remedial actions required if both impact and levels were confirmed.

Determination of any potential environmental impact would rely upon the EPA list of "Lowest Reported Toxic Concentrations" for contaminants that have been shown to cause impacts on appropriate target species in the marine environment. The dilution factor would be established using the monitoring data from the wells in the center of south berm, the berm face wells just inside the berm face, and measurements of the surface seawater adjoining the south berm face. It would be used to relate the well concentration to the probable concentration expected at the point of compliance (the south berm face). In all cases, a statistical analysis using at least four samples would be necessary to determine if the results from the samples were significantly above the threshold levels.

In practice, the first threshold level would be handled by notification and discussions of potential environmental impact. However, the agencies reserved the right to implement further action if it was determined that there was a potential impact from the contaminated dredge material. The second threshold level would trigger the same notification as the first level, however a higher level of response would be considered.

V.3 REMEDIAL ACTION PLAN

According to the Plan, all remedial action decisions would be based on results from replicated sampling. The measured levels would have to be statistically greater than the threshold. Elevated levels would also have to be demonstrated to be from the contaminated dredged materials. Remedial actions would then be implemented in an incremental fashion. The increments include:

- Hold the upgradient water level in the pond at mean tide (+6.6 feet). This would eliminate the advective flow through the fill.
- Pump the interstitial water out of the fill and discharge to a Metro sewer (an interim measure). This would minimize water flow seaward through the south berm.

- Chemical stabilization if possible. This depends on the contaminant. This is a new technique and would be used only if new information showed it to be acceptable for the specific contaminant causing concern.
- Build a slurry wall in the north and south berms.
- Build a slurry wall in the east and west berms.
- Remove the contaminated dredged material from between the berms.

The appropriate initial increment would be chosen by mutual agreement between WDOE, EPA, the Army Corps, and the Port. A sampling and analysis program to determine the effectiveness of each increment would be implemented. Each step would be evaluated through sampling and analysis before a determination as to whether a further remedial action would be needed.

V.4 MONITORING PROGRAM

The results from the Phase I modeling report (Appendix A.1) were used to help determine monitoring well location and sampling depth. Well depths coincided with the hydraulically active upper layer in the inter-tidal zone, the shallowest layer of the fill below the inter-tidal zone, and the deeper fill layer. Ten well locations were initially chosen along with six water sampling stations. Four of the well locations were designed as nested groups of wells (three wells per group) for a proposed total of 18 sampling wells. All of the monitoring wells and sampling stations proposed in the Plan can be seen in Figure 1.

Well locations were chosen to best monitor the performance of the system in terms of hydraulic flow and contaminant concentrations. This information would be used to:

- Monitor for water quality violations based on the criteria and thresholds, and
- Verify the pre-project modeling and re-evaluate long range predications.

The Plan's schedule of monitoring activities included:

- Sampling after the dredged material was placed in the site and before it was surcharged with the clean fill cap;
- Monthly sampling for the first six months after the dredged material was in place and covered;
- Quarterly sampling for the following two years;
- Semi-annual sampling for the following two and one-half years; and
- Special research-oriented sampling for low-level organics and close-interval sampling over a tidal cycle.

SECTION VI

SHORT FILL CONSTRUCTION AND WELL SYSTEM INSTALLATION

VI.1 SHORT FILL CONSTRUCTION

Following approval by Ecology and selection of a contractor, the Short Fill construction began during the summer of 1986. The Short Fill consists of two berms connecting piers 90 and 91 with dredged material placed between them, as shown in Figures 1 and 2. The berms are long mounds with a sandy gravel (structural fill) core covered with rip rap. The contaminated dredged material fill was placed between the berms before being topped with uncontaminated structural fill and finally paved with asphalt. A stormwater system was also installed to drain the paved asphalt surface.

The north berm was constructed first using barged-in structural fill material specified as primarily a sand-gravel mixture with some fines, and rip rap. The lifts of rip rap were placed first to create the outer berm shell. Then the structural fill lifts were placed between the rip rap shell using a barge-mounted drag line. This was continued in stages until the design height for the berm was achieved. The south berm was then constructed in a similar manner with the addition of a notch or gap in the center to facilitate placement of the dredged material fill via bottom dump barge.

The north berm was purposely constructed so that the northern toe of the berm was at least 75 feet from the southern-most row of bridge column supports for the Magnolia Bridge which supports West Garfield Street (Figure 1 and 2). This was done so that the consolidation of the prevalent deep silt layer, caused by the weight of the berm and fill, would not affect the structural integrity of the bridge. By moving the Short Fill back from the Magnolia Bridge, a pond was created in the slip between piers 90 and 91 just north of the Short Fill. This pond has been named the North Pond for use in this report.

Following berm construction, the majority of the dredged fill was placed by bottom dump barge. A silt curtain was placed across the notch in the south berm to contain suspended dredge material during the filling operations. The curtain was opened only to allow the barge to enter and exit the fill. When the barge could no longer enter the fill due to its draft, the notch was completed as part of the south berm.

Because the Port expansion projects did not proceed as planned, Corps of Engineers maintenance dredged materials unsuitable for open-water disposal was used to help complete the fill. This material was placed by dragline bucket over the completed south berm. Even with the addition of the Corps of Engineers maintenance dredge material, the top of the fill was lower than planned.

Due to delays in construction contracting, the dredged fill lay uncapped for about six months. Early on during the six month delay, the fill consolidated and the free standing water over the dredge material clarified as the fines settled out. At this time the North Pond was not at its final static water level height since the upper cap was not yet in place. Therefore, the hydraulic gradient from the pond through the fill was minimal so there would have been very little if any transport of the free standing surface water from the fill into the 90/91 slip through the south berm. In fact, testing of the free standing water after fourteen weeks showed that the water quality was identical to the adjoining 90/91 slip. The surface water also showed minimal tidal fluctuations indicating minimal interaction through the south berm.

During the six-month delay, a small amount of clean beach material from the adjacent upland-excavation-beach-creation project was placed in the fill. This project was required as part of the mitigation for the intertidal area being covered by the Short Fill. This beach material was pushed out from Pier 91 along the west side of the fill and in the northeast corner of the fill from Pier 90. This technique produced a small "mud wave" in front of the deposited beach material creating a somewhat uneven surface, especially on the west side of the fill. The remaining beach material was stockpiled on the north and south berms to be use as cap material.

After the six-month delay period, the contractor pumped off the free standing water in preparation to placing the cap material over the fill. The remaining beach material and cap material were pushed out and dumped using specialized, small, light weight mud cats with front-end loaders, instead of the drag lines originally planned. This allowed the cap material to be spread evenly in layers over the fill, working outward from the berms.

The six-month delay of the fill and removal of the overlying water reduced the volume of dewatering resulting from cap placement and surcharge as predicted by the Phase I modeling study. The dewatering that did take place occurred over a shorter period of time than was anticipated in the initial CTMRAP monitoring schedule and before all of the monitoring wells could be installed. Stockpiling of the beach and cap material on the berms also precluded well installation immediately following berm construction. Only a limited number of wells were available to monitor the initial dewatering and consequently there are only a limited number of surveys and results cover the dewatering period for the Short Fill.

VI.2 WELL SYSTEM INSTALLATION

The results from the Phase I modeling report (Appendix A.1) were used to help determine monitoring well locations and screening depths. Well screening depths corresponded with the hydraulically active upper layer in the inter-tidal zone, the shallowest layer of the fill below the inter-tidal zone, and the deeper fill layer. The wells locations were positioned to monitor groundwater flowing into, within, and from the fill. These wells would be placed in the berms, the contaminated dredge material fill, the structural fill cap, upgradient of the Short Fill and the North Pond just north of the Magnolia Bridge, and in Pier 91. Actual installed well locations are shown in Figure 2.

Three stages of monitoring well installation were planned which corresponded to the phases of the Short Fill construction. The first set of monitoring wells was installed during late October, 1986, during placement of the cap. The first set includes wells W-2, W-3, W-4A, W-4B, W-4C (south berm wells), W-7A, W-7B, W-7C (north berm wells), W-9 (Pier 91) and W-10 (upgradient).

A second set of wells was installed in April, 1987, following final cap placement and surcharge, just prior to paving. These wells could not be installed until consolidation of the fill had occurred. Prior installation would have damaged the wells. These wells include W-5A ("clean" structural fill cap), W-5B and W-5C (contaminated dredge material fill) and W-6 (mixture of "clean" structural fill and contaminated dredge material fill).

A third set of wells was originally planned along the face of the south berm. These wells were to have monitored contaminant concentrations just before they exited from the berm. However these wells were not installed as the result of an oil spill prior to their installation in September of 1986. In that spill, more than 3,000 gallons of oil were released into the 90/91 slip during vessel operations at Pier 91. Oil penetrated the south berm to a depth of several feet. Even though a portion of the south berm face was removed, a small amount of oil remained in the berm and continued to produce thin oil sheens for several months.

Because of the potential for masking true contaminant concentrations by this and other possible future spills, the south berm face wells were not installed. This was no doubt an appropriate decision since another small oil spill of unknown origin was observed in the slip several months following the larger spill, which further complicated monitoring along the south berm face. Berm face wells are now planned only if needed to quantify a specific contaminant. The south berm wells installed along the axis of the south berm crest (W-2, W-3, W-4A, W-4B, W-4C) would be used to monitor discharge and contaminant concentrations in the south berm.

SECTION VII

MONITORING PROGRAM

VII.1 SITE DESCRIPTION

As part of the CTMRAP monitoring program, ten well locations were initially chosen along with six water sampling stations (Figure 1). Four of the well locations were designed as nested groups of wells (three wells per group) for a proposed total of 18 sampling wells.

Two of the well locations were not actually installed and two of the sampling stations were not actually used as initially planned (Figure 1). The proposed nested well location (W-1) just inside the south berm face was not installed as discussed in the previous section VI. The pier 90 well (W-8) was not installed because pier 90 was relatively impermeable based on data from previous borings and was not an important pathway for contaminants. The pier 91 well (W-9) was installed after a gravel lens was observed during soil borings at the W-9 location. Well W-9 was completed in the gravel lens which was later determined not to be an important pathway based on the measured low permeability of the material from the gravel lens. Also two water sampling stations (stations 12 and 13), one each on the outside of piers 90 and 91, were dropped from the original plan (Figure 1). These two stations were dropped because modeling results showed the side berms were not a major pathway.

The wells actually used in the monitoring program were:

- South Berm: W-2, W-3, W-4A, W-4B, W-4C
- North Berm: W-7A, W-7B, W-7C
- Dredge Fill: W-5B, W-5C
- Cap: W-5A
- South Berm/Fill/Cap: W-6
- Pier 91: W-9
- Upgradient: W-10

The water sampling stations actually used were:

- 90/91 Slip: 14, 15, 16
- North Pond: 11

Samples at station 14 were collected next to the south berm just below the surface at low tide. Station 15 and 16 samples were collected from just below the surface. Station 11 samples were collected from the North Pond next to the north berm just below the surface (station 11s). In addition, occasional station 11 North Pond samples were collected from below the summer thermocline (station 11d).

VII.2 MONITORING ACTIVITIES

Table 1 is a list of the sampling surveys and dates, the wells and stations sampled, the analyses performed, and the purpose of each survey. The purpose of each survey follows the CTMRAP monitoring program (section V, Appendix A.2). The exceptions are for surveys CTM 12 and CTM 13.

CTM 12 was conducted to re-analyze metals from CTM 11 using the same analytical techniques as were used in the previous surveys. Different analytical techniques which did not meet quality control guidelines for metals, were inadvertently used in CTM 11. Therefore, most stations were re-sampled during CTM 12 to insure consistency so that all monitoring results could be included in the final performance criteria statistical analysis.

CTM 13 (Appendix F) was conducted to determine the cause of the elevated metals concentrations measured in the cap pore water which were discovered following a preliminary review of the monitoring data. This was a concern because well W-5A is located in the permeable gravelly-sand structural cap material overlying the much less permeable dredged material fill and could potentially act as a pathway for transporting contaminants from the fill, through the cap and berm, and into the accessible environment.

The Plan's scheduled monitoring activities included:

- Sampling after the dredged material was placed in the site and before it was surcharged with the clean structural fill cap;
- Monthly sampling for the first six months after the dredged material was in place and covered;
- Quarterly sampling for the following two years;
- Semi-annual sampling for the following two and one-half years; and
- Special research-oriented sampling for low-level organics and close-interval sampling over a tidal cycle.

The original monitoring schedule outlined in the Plan was intended to be flexible so that it could be modified to reflect changes in construction techniques and progress, and to allow a reduction in monitoring if no problems were seen for specific wells or stations. The actual monitoring schedule and activities are shown in Figure 1. Specific changes made in the original schedule were:

- No initial monitoring of the north berm prior to closing the south berm. The north berm was inaccessible due to the stockpiling of the clean material from the beach mitigation on the berm.

- The four scheduled routine monthly surveys during dewatering were cut to three since the dewatering time would be less because the initial consolidation had already occurred during the six month construction delay.
- The five scheduled routine quarterly surveys were cut to three because the initial survey results showed only a slow rate of change over time.
- The five scheduled routine semi-annual surveys were cut to two because the initial survey results showed only a slow rate of change over time. The semi-annual surveys would be interspersed with the high resolution tidal and low level priority pollutant surveys.
- The high resolution tidal and low level priority pollutant surveys were rescheduled from the beginning of the program until toward the end.

Table 1 – Terminal 91 Short-Fill Monitoring
Sampling and Analyses Schedule

Station/Well:		2	3	4a	4b	4c	5a	5b	5c	6	7a	7b	7c	9	10	11s	11d	14	15	16	Analyses	Purpose
Survey	Date																					
CTM 1	11/26/86	X		X	X																Some metals + Organics	Monthly Monitoring
CTM 2	12/10/86	X	X	X	X	X					X	X	X	X	X	X		X	X	X	Metals + Organics	Monthly Monitoring
CTM 3	01/23/87	X	X	X	X	X					X	X	X		X	X		X	X	X	Metals	Monthly Monitoring
CTM 4	05/12/87	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X	Metals + Organics	Quarterly Monitoring
CTM 5	10/28/87	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	Metals, TOC	Quarterly Monitoring
CTM 6	01/28/88	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	Metals, TOC + Organics	Quarterly Monitoring
CTM 7	05/06/88	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	Metals, TOC	Semi-Annual Monitoring
CTM 8	07/28/88			X	X	X	X	X	X	X	X	X				X		X			Some metals, TOC, pH	25-Hr Tidal Survey
CTM 9	12/30/88					X		X										X			Organics, Control Stations	High Resolution Survey
CTM 10	07/31/89	X		X	X	X	X	X	X	X						X		X			Inorganic-N, TOC, and Metals at 4b	25-Hr Tidal Survey
CTM 11	08/22/90	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Metals + Organics	Semi-Annual Monitoring
CTM 12	02/12/91	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X			Metals, TOC, Cond., Alk., Sulfate, Sulfide, pH, Eh, Ferrous Fe, Diss. Oxygen, Temp.	Repeat Metals from CTM 11
CTM 13	01/20/92						X	X	X	X											Metals, Cond, Alk, Sulfate, Sulfide, pH, Eh, Ferrous Fe, Temp., Inorganic Nitrogen, chloride salinity, tannin and lignin, CO2, CH4, H2S, O2	Measure Gases Monitor Dissolved and Raw Metal Concentrations

SECTION VIII

MONITORING PROGRAM RESULTS

VIII.1 COMPARISON WITH PERFORMANCE CRITERIA

In the CTMRAP agreement, performance criteria were established as either the 1985 EPA chronic marine water quality criteria, or ten times background seawater concentration for contaminants without established EPA criteria. The criteria would be applied to the long-term average (i.e. chronic) concentration at the point of compliance which was established as the south berm face.

The compliance wells originally planned for the south berm face, well cluster W-1, were not installed due to the petroleum spill problems discussed in section VI. Instead, compliance monitoring data from the south berm crest wells: W-2, W-3, W-4A, W-4B, and W-4C would be used, and the berm face sample was changed to be taken as close to the berm face rock as possible. In accordance with CTMRAP, a dilution factor would be used to relate the south berm crest monitoring well concentration to the probable concentration expected at the point of compliance (i.e. the south berm face). The dilution ratio estimated in the Phase II modeling report (Appendix D) was 5:1 from the south berm crest to the south berm face. This ratio indicates that the water from the south berm crest wells is diluted in the ratio 1 part berm crest water to 5 parts of 90/91 slip water at the berm face. This dilution ratio can be used along with contaminant concentrations in the south berm crest wells and 90/91 slip water to determine the dilution at the berm face.

In order to determine if compliance has been met, the monitoring data from the south berm crest wells were first screened to determine if any contaminants were above the performance criteria. If any results from an individual well were above the criteria, all of the survey results from that well would be combined and statistically compared to the performance criteria. If this comparison indicated results significantly above the performance criteria, the 5:1 berm crest:berm face dilution ratio was then applied to determine performance at the point of compliance at the south berm face.

Detailed screening of the organic results from the south berm crest wells showed only a single result flagged as an estimated value from well 4A. This compound showed up during the CTM 4 survey and was tentatively identified as bis(2-ethylhexyl)phthalate, which is a common laboratory contaminant from plastics. All of the remaining organics results were below detection in the south berm crest wells during all of the surveys, including the low-level organics survey during CTM 9. Therefore the organics monitoring data from the south berm crest wells clearly demonstrate that the Short Fill has exceeded the performance criteria for organics.

However, unlike the organics, preliminary screening the metals data revealed a number of individual values from the south berm crest wells at or above the performance criteria for nickel, zinc, mercury, barium, and manganese. The following table (Table 2) lists the performance criteria used in screening the metals data. All values are in mg/L with

performance criteria established by EPA chronic water quality criteria indicated as "(EPA)". All other values are roughly ten times the average concentration of the seawater background stations 14, 15, and 16.

Table 2 - Metals Performance Screening Criteria (mg/L)

<u>Metal</u>	<u>Screening Criteria</u>	<u>Metal</u>	<u>Screening Criteria</u>
Al	1.06	Li	2.60
Sb	0.01	Mn	0.07
As	0.036 (EPA)	Hg	0.000025 (EPA)
Ba	0.07	Mo	0.40
Be	0.03	Ni	0.0071 (EPA)
Bi	5.00	P	18.54
B	33.00	Se	0.01
Cd	0.0093 (EPA)	Si	42.92
Cr	0.050 (EPA)	Ag	0.01
Co	0.20	Sr	56.04
Cu	0.03	Sn	0.30
Fe	0.87	Ti	0.06
Pb	0.01	Tl	0.01
V	0.37	Zn	0.058 (EPA)

Monitoring results above the criteria for the south berm crest wells were tagged for further statistical analysis. These wells and contaminants were then used to determine if the south berm crest well concentrations were significantly above the performance criteria at the 5% significance level.

Tables 3, 4, and 5 give the results of the statistical analysis for the metals data above the performance criteria from the south berm crest wells. Table 3 compares the results with the fixed EPA chronic criteria for nickel, zinc, and mercury, while Tables 4 and 5 compare the manganese and barium results with ten times the background concentration as the performance criteria.

Table 3 – Performance Criteria Statistical Analysis
Comparison with EPA Criteria

Compliance ell	Well 3	Well 4A	Well 4A	Well 4B	Well 4C	Well 7C*	Well 7B*
Metal	Ni	Hg	Zn	Ni	Ni	Ni	Ni
<u>Survey</u>							
CTM 1	<	0.00005	0.029 <	0.001			
CTM 2	0.016 <	0.00005	0.025	0.006	0.110	0.074	0.025
CTM 3	0.010	0.00009	0.045	0.004	0.120	0.035	0.014
CTM 4	0.013 <	0.00005	0.020	0.009	0.100	0.014	0.011
CTM 5	< 0.001 <	0.00005	0.049	0.004	0.084	0.008	0.012
CTM 6	0.005 <	0.00005	0.077 <	0.001	0.099	0.009	0.009
CTM 7	0.011 <	0.00005	0.002	0.002	0.085	0.007	0.010
CTM 9				< 0.007			
CTM 12	0.004 <	0.00005 <	0.001 <	0.001	0.047	0.007	0.009
Count	7	8	8	9	7	7	7
Ave	0.009	0.00006	0.031	0.004	0.092	0.022	0.013
Std. Deviation	0.005	0.00001	0.025	0.003	0.024	0.025	0.006
CV	0.628	0.257	0.821	0.755	0.257	1.137	0.439
Normal Dist.?	YES	YES	YES	YES	YES	NO	YES
Tn	1.38	2.47	1.81	1.74	1.18	2.08	2.15
Outlier?	NO	YES	NO	NO	NO	YES	YES
Ave MDL	0.009	NA	0.031	0.003	0.092	0.022	0.013
Std MDL	0.005	NA	0.025	0.003	0.024	0.025	0.006
Lower 95% CI	0.005	0.00005	0.014	0.002	0.075	0.004	0.009
Higher 95% CI	0.012	0.00006	0.048	0.005	0.110	0.040	0.017
Criteria	0.0071	0.000025	0.058	0.0071	0.0071	0.0071	0.0071
Exceeds Criteria	NO	NA	NO	NO	YES	NO	YES

Source: Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities – Interim Final Guidance (USEPA, 1989)

MDL: Multiple Detection Limit using Robust Log-Probability Regression (Helsel & Cohen, 1988)

NA: Not Appropriate

* Wells 7B and 7C are in the north berm and are NOT Compliance Wells and are shown for comparison only

Table 4 – Performance Criteria Statistical Analysis
MANGANESE (ppm)

BACKGROUND STATIONS			COMPLIANCE WELLS									
Date	Conc.		Well 2		Well 3		Well 4A		Well 4B		Well 4C	
	x10	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank
<u>Sta. 14</u>												
01/23/87	<0.003	11	<0.003	11	<0.003	11	<0.003	11	<0.003	11	10.900	43
05/12/87	<0.003	11	<0.003	11	1.330	39	<0.003	11	0.250	35	11.900	44
10/28/87	<0.003	11	<0.003	11	2.120	40	<0.003	11	0.210	34	8.610	42
01/28/88	0.050	29.5	0.009	24	0.480	36	0.003	11	0.011	25	14.600	45
05/06/88	0.180	32	<0.003	11	1.150	38	<0.003	11	0.013	26	14.800	46
07/31/88									0.203	33		
02/12/91	0.120	31	0.003	11	0.680	37	0.005	22.5	0.005	22.5	7.770	41
<u>Sta. 15</u>												
01/23/87	<0.003	11										
10/28/87	<0.003	11										
01/28/88	0.040	27.5										
05/06/88	0.040	27.5										
<u>Sta. 16</u>												
01/23/87	<0.003	11										
05/12/87	<0.003	11										
10/28/87	<0.003	11										
01/28/88	<0.003	11										
05/06/88	0.050	29.5										
<u>STEPS 1 & 2</u>												
No. Observations:		15		6		6		6		7		6
Sum of Ranks:		276.0		79.0		201.0		77.5		186.5		261.0
Average rank:		18.4		13.2		33.5		12.9		26.6		43.5
<u>STEPS 3 & 4</u>												
No. of Wells (K)		6										
Total Observations:		46										
Krusal – Wallis H'		36.97										
X ² ; H ₀ (P=.95)		11.07										
Contamination? (H' > X ²)	YES											
<u>STEPS 5 & 6</u>												
Z Value		2.3263										
Critical Value				14.76		14.76		14.76		13.99		14.76
Difference (Well – Background)				-5.23		15.10		-5.48		8.24		25.10
Diff. Exceeds Critical Value?			NO		YES		NO		NO		YES	

Well 3 broken after the first measurement, see text for details

Source: Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities – Interim Final Guidance (USEPA, 1989)

Table 5 – Performance Criteria Statistical Analysis
BARIUM (ppm)

BACKGROUND STATIONS			COMPLIANCE WELLS									
Date	Conc.		Well 2		Well 3		Well 4A		Well 4B		Well 4C	
	x10	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank
<u>Sta. 14</u>												
01/23/87	0.150	40.5	0.120	31	0.130	33.5	0.150	40.5	0.130	33.5	0.150	40.5
05/12/87	0.280	45	0.100	23.5	0.091	18.5	0.110	27.5	0.130	33.5	0.092	20
10/28/87	0.070	10	0.110	27.5	0.160	43	0.110	27.5	0.170	44	0.093	21
01/28/88	0.110	27.5	0.086	15	0.140	37	0.089	16	0.140	37	0.096	22
05/06/88	0.080	14	0.075	13	0.140	37	0.072	12	0.150	40.5	0.100	23.5
02/12/91	0.060	5.5	0.110	27.5	0.130	33.5	0.055	2	0.110	27.5	0.091	18.5
<u>Sta. 15</u>												
01/23/87	0.060	5.5										
10/28/87	0.060	5.5										
01/28/88	0.060	5.5										
05/06/88	0.050	1										
<u>Sta. 16</u>												
01/23/87	0.070	10										
05/12/87	0.060	5.5										
10/28/87	0.090	17										
01/28/88	0.060	5.5										
05/06/88	0.070	10										
<u>STEPS 1 & 2</u>												
No. Observations:		15		6		6		6		6		6
Sum of Ranks:		208.0		137.5		202.5		125.5		216.0		145.5
Average rank:		13.9		22.9		33.8		20.9		36.0		24.3
<u>STEPS 3 & 4</u>												
No. of Wells (K)		6										
Total Observations:		45										
Krusal-Wallis H'		24.57										
X ² ; Ho (P=.95)		11.07										
Contamination? (H'>X ²)	YES											
<u>STEPS 5 & 6</u>												
Z Value		2.3263										
Critical Value			14.43		14.43		14.43		14.43		14.43	
Difference (Well – Background)			9.05		19.88		7.05		22.13		10.38	
Diff. Exceeds Critical Value?			NO		YES		NO		YES		NO	

Source: Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities – Interim Final Guidance (USEPA, 1989)

Two different statistical analyses were required in the comparative analysis since the EPA criteria are fixed values with no variability, while the background data are based on averages from sampled data which do contain variability. Both of the statistical analyses are based on the approaches given by EPA (USEPA, 1989) for use with groundwater monitoring data. Table 3 also uses a method suggested by the U.S. Geological Survey (Helsel and Cohen, 1988) for determining statistics from data containing multiple detection limits (MDL).

Comparison of the monitoring results with the EPA chronic saltwater criteria (Table 3) involve determining the 95% confidence interval for each of the south berm crest wells and comparing the lower 95% interval with the criteria. This comparison was performed for nickel (wells 3, 4B, W-4C), zinc (well 4A), and mercury (well 4A). Other values listed in Table 3 are results of intermediate tests required in the analysis. These values include the coefficient of variation (CV) which tests for a normal distribution, and a test to determine if any high values may be "outliers" based on the Tn statistic at the 95% confidence level (USEPA, 1989).

Analysis of the statistical results (Table 3) shows that even without a dilution factor, wells 3 and 4B do not significantly exceed the performance criteria for nickel and well 4A does not significantly exceed the criteria for zinc.

There was only one mercury value above the detection limit at 0.00009 mg/L in well 4B, the other seven values were below the detection limit of 0.00005 mg/l which is above the 0.000025 mg/L EPA chronic saltwater criteria level (Table 3). With seven out of eight the non-detect values, and with the detection limit above the performance criteria, quantitative statistical analysis could not be performed on this data set.

However a simple non-statistical argument can be made that these mercury results are likely to meet the performance criteria. We can argue that even if the one mercury value above the detection limit was real (although it statistically appears to be an outlier), and we conservatively assume that all other non-detect values were at the detection limit rather than below it, then the average value before dilution would only be 0.00006 mg/L. Now if we apply the dilution of 5:1 with 90/91 slip water, this value would be diluted to below the EPA chronic saltwater criteria at the berm face assuming that the actual concentration of 90/91 slip water is about 0.00002 mg/L or less. 90/91 slip water is probably below this level. For example, seawater values from Puget Sound used in the Phase II modeling as representing 90/91 slip water were 0.000015 mg/L. Therefore, regardless if we either eliminate the outlier value or include it, we can conservatively estimate that the Short Fill will meet the performance criteria for mercury.

Another more probable yet less conservative approach would be to consider that all the mercury values are non-detect (outlier thrown out) and that the value is somewhere between zero and the detection limit. If the value was one-half the method detection limit as suggested as an approach in the compliance monitoring sections of the Washington State Model Toxics Control Act (WAC Chapter 173-340), then the berm crest wells would meet the EPA chronic criteria without dilution.

Excluding the one mercury outlier from well 4B, the only south berm crest well which significantly exceeded the EPA criteria was well W-4C for nickel. Even with the dilution factor, this well significantly exceeds the criteria. However, before remedial actions can be considered, CTMRAP requires demonstrated confirmation that the contaminant comes from the contaminated dredge material fill, and that the contaminant has been shown to cause a problem in the marine environment.

Therefore, regarding the significant nickel concentrations in well W-4C, the questions to consider are:

- 1) Is the nickel from the contaminated dredge material fill, and if it is,
- 2) Does it pose a problem for the marine environment.

The first question can be easily answered by looking at the monitoring data from the fill (wells W-5B and W-5C). These data (see Appendix C) indicate that levels of nickel in the groundwater from the dredge material fill are generally at or below the detection limit of 0.001 mg/L. Of the ten values measured during the monitoring program, eight are below detection, one at the detection limit, and one at 0.002 mg/L. This is not surprising since the nickel should be bound up in the very insoluble sulfide compounds within the fill. Therefore the source of nickel in well W-4C is not the contaminated dredge material fill, which, according to the CTMRAP agreement, means that the question of potential environmental effects need not be considered.

However, an important question still remains as to the actual source and release mechanism causing the higher nickel concentrations in well W-4C. The most likely source of nickel is the clean structural berm material itself. A reasonable scenario describing how this can occur is presented below using the nickel data in Table 3.

In developing the scenario to explain the higher nickel levels in well W-4C, we will use wells W-4C and W-7C which are located in opposite ends of the Short Fill at about the same depth in the center of the south and north berms, respectively (Figure 2). The data from the wells show a decreasing trend in nickel over time with higher levels occurring following capping of the fill and the resultant dewatering during CTM 2 and 3 (Table 1). Since dewatering mainly occurred through the more permeable berms, and since there is essentially no nickel in the water from the dredge material fill, the results suggest that the seawater from the fill and/or from the 90/91 slip could contain other constituents which react with the berm material to release or leach nickel from the berm.

Release of nickel and many other metals would generally be expected to occur anywhere in the Short Fill where solutions and materials from significantly different geochemical environments (such as the more oxidizing fresher water from the pond and the reducing water in the fill) interact. This would be the case for the initial placement of the structural berm material which is composed of sand and gravel originally from an aerobic oxidizing and unsaturated environment being placed into a saturated environment much richer in organics and reducing compounds. In this case we would expect that some of the oxidized metal oxyhydroxide coatings on the sand and gravel of the berm material

would be reduced and released into solution within the berm following placement in seawater. Release would continue until either a new equilibrium condition in the new environment had been attained or until the source of metal or reducing agent had been depleted.

During dewatering, when the more "corrosive" saltwater from the fill passes through the berms, nickel is leached from the berm material into the groundwater within the berms. As the fill reaches its final consolidated state, the outward flow of the fill water stops and a much slower flow of water through the Short Fill system from north to south takes over. This slower north to south flow is produced by the hydraulic gradient between the higher water levels in the North Pond relative to the mean water level in the 90/91 slip. This flow causes the fresher water from the North Pond to slowly enter the Short Fill through the north berm and cap.

This change from a rapid outward dewatering flow of saltwater from the fill to a slower inward freshwater flow from the North Pond is evidenced by the decrease in saltwater constituents in the monitoring data from the north berm well W-7C. Assuming that the fresher water from the North Pond is less corrosive or reactive with the berm material than the saltwater, we would expect nickel concentrations in well W-7C from the north berm to drop more quickly following dewatering due to the influx of the fresher, less corrosive North Pond water than in well W-4C from the south berm which is still being slowly leached by saltwater from the fill. This is exactly what is seen in the monitoring data (Table 3). It should be noted however, that it is impossible to distinguish between the corrosive nature of the saltwater from the fill and the saltwater from the surrounding marine waters in the 90/91 slip based on the existing data. Nevertheless, this scenario readily explains the source and mechanism of the higher nickel concentrations in well W-4C and serves as a working hypothesis to assist in determining the source of other metal contaminants in the south berm.

Table 4 gives the statistical analysis for manganese. The steps outlined and numbered in the table are directly from the EPA reference (USEPA, 1989 pages 5-14, 5-15). This statistical approach is technically described as a one-way nonparametric analysis of variance rank-sum procedure which uses the Kruskal-Wallis test. This approach handles detection limit values and is not dependent upon an underlying distribution assumption. It is most useful for inter-well comparisons. Ten times the concentration levels from the background stations (14, 15, and 16) are compared to the south berm crest wells. The test is for a significant difference between the berm wells and the background stations at the 5% significance level.

Based on the analysis in Table 4, a significant difference in manganese was detected for well 3 and W-4C. These concentrations would still be significantly above the criteria after dilution. Relative to CTMRAP, the questions to consider are once again:

- 1) Is the manganese from the fill, and if it is,
- 2) Does it pose a problem for the marine environment.

We will use our previous working hypothesis scenario to answer the first question.

The data from the potential source wells in the contaminated dredge material fill (wells W-5B and 5C) show manganese concentrations less than 2 mg/L, ranging from 0.75 to 1.6 mg/L. Concentrations in well 3 range from <0.003 to 2.1 mg/L, and well W-4C range from about 8 to 15 mg/L. Using our working hypothesis, this data suggests that the fill may be a potential source for some of the manganese in well 3 while most of the manganese in well W-4C is derived from leaching of the berm material. This conclusion for well W-4C is supported by the monitoring data from well W-7C which shows that concentrations in well W-7C have decreased over time from 8.7 to .37 mg/L.

However, for well 3, Table 4 also indicates that well 3 was broken following the first measurement. As noted in Table 4, sometime between January and May of 1987, the upper PVC casing in well 3 was accidentally broken during the final cap construction. The anomalously high manganese levels in well W-3 relative to the equivalent undamaged well W-4B coincide with the period following the damage to well W-3. The damaged upper well casing was repaired and an attempt was made to clean out the debris from the well. However, the in-situ pump could not be extracted from the well since it was wedged in by the gravel from the berm which had entered the broken well. Consequently we know that the damage and repair of well W-3 allowed the sands and gravel from the berm to enter the well. Based on this information, the monitoring data strongly suggests that the anomalously high manganese concentrations in well W-3 are most likely attributable to release from the sand and gravel within well W-3 derived from the berm and not from the fill.

Therefore the answer to the first question is no, the source of most of the manganese is the berm material and not the contaminated dredge material fill. However, even considering that a small portion of the total manganese may be from the fill, the answer to the second question, does manganese at these concentrations pose a problem to the environment, is no; it does not directly pose a problem. In fact manganese is a vital micro-nutrient for both plants and animals. There are no established chronic or acute water quality criteria for manganese. The only published criteria for manganese is a recommended criterion of 0.1 mg/L for marine waters to protect against possible human health effects from bioaccumulation in shellfish (USEPA, 1986).

Table 5 gives the results of the statistical analysis for barium. This is the same methodology used for manganese in Table 4. The analysis indicates that the south berm crest wells W-3 and W-4B are significantly greater than the ten times background criteria. Concentrations in the potential source water from the fill (wells W-5B and 5C) range from 0.65 to 2.9 mg/L indicating that the fill is a potential source. However, using a dilution ratio of 5:1 and an average 90/91 slip water concentration of 0.009 mg/L, concentrations from both wells W-3 and W-4B would be diluted to below the performance criteria of ten times background or 0.09 mg/L. Consequently, barium would not be considered to be above the performance criteria. In any case, barium is not considered a problem to aquatic life in terms of toxicity in concentrations under 50 mg/L (USEPA, 1986).

VIII.2 MODELING FOLLOW-UP

After the completed facility had been monitored for four years, a Phase II modeling study was conducted (PGG/CCNW, 1990 and Appendix D). This study updated the previous model using the actual as-built dimensions, current understanding of contaminant behavior, and measured hydraulic (Hart Crowser, 1988 and Appendix B) and chemical monitoring results (Appendix C).

The results indicated that concentrations of contaminants entering the water would be less than previously predicted in the Phase I modeling (Appendix A.1). This was due in part to the fact that the contaminated fill material contained lower concentrations than the conservative worst-case estimates used in the Phase I modeling. However, the percentage of the total amount of contamination in the Short Fill which would be leached during the first 100 years of operation were predicted to increase. The total percentage leached still was generally less than one percent in the Phase II modeling compared to less than 0.5 percent previously predicted in the Phase I modeling. The relatively higher percentage resulted primarily from a larger hydraulic transport due to physical changes in the as-built system.

this method of confined disposal for contaminated dredge material. The CTMRAP approach would be appropriate for monitoring and evaluating other near-shore disposal sites.

In summary, the Short Fill project has fulfilled its original purposes, given insight into the mechanisms of contaminant containment, and provided information that can be applied to other sites. To the best of our knowledge, the facility is the first of its kind in the U.S. to be extensively modeled and monitored, and as such, is viewed as a demonstration project. The design studies and monitoring program were designed to lay the groundwork for future near-shore confined disposal facilities, allowing for an efficient regulatory and technical process.

SECTION X

LESSONS LEARNED AND APPLICABILITY TO OTHER SITES

Over five years of monitoring, two computer modelling studies and the analyses for this report have generated considerable insight and lessons that apply to the this and future projects. These lessons and their applicability to other projects are discussed below.

X.1 LESSONS LEARNED

X.1.a Containment

The Short Fill project demonstrates that containment of contaminated dredge material with limited release meets the regulatory and environmental requirements laid out in the performance criteria of the CTMRAP agreement between the Port of Seattle and the Department of Ecology. Measured concentrations of both inorganic and organic contaminants in the south berm crest wells meet the performance criteria as discussed in section VIII. In addition, modeling results indicate that the existing standards will not be exceeded over the 100 year period of the analysis.

Physical containment works due to the combination of a high-permeability berm and low-permeability dredge materials. The low permeability of the dredge materials limits flow rates. Low flow rates help maintain the anaerobic conditions within the contaminated dredge material fill which in turn produces minimal release of most metals and organics. The high-permeability berm allows fresh oxygenated seawater to enter deep into the berm due to tidal action. As will be discussed below, this allows biogeochemical processes to occur deep within the berm which contain the contaminants within the berm. Together the berm/fill combination produces low rates of low concentration discharge into the berm from the fill.

The berm plays a very important role in trapping and containing trace metals. Without the berm, steep chemical gradients for most trace metals would occur at the fill/seawater interface where metals bound in sulfide compounds within the anaerobic fill would be oxidized and released, causing relatively high concentrations near the interface. However, within the tidally active portions of the berm, the effects of dispersion and tidal mixing with oxygenated seawater create a situation analogous to a sand filter water treatment system. Within the tidally active portions of the berm, the water from the fill is mixed with the oxygenated seawater from the 90/91 slip which enhances metal oxidation and removal by forming insoluble metal oxides, especially iron oxyhydroxides. These metal oxide compounds are captured on the surfaces of the berm material which acts as trap to contain and hold the metal oxides within the berm. In addition, these compounds are also surface-active which means they will continue to scavenge additional trace metals from solution by surface sorption and precipitation. In fact, iron oxide coated sands have been shown to be an effective adsorbent-filtration media for treatment of soluble and particulate heavy metals from groundwater at a Superfund site (Benjamin and Sletten, 1992).

The berm will also serve as a trap for any colloidal transport from the facility. Colloids would be stabilized in solution under freshwater reducing conditions within the cap (Appendix F) and eventually within the fill as it becomes fresh. However, once these colloids reach the oxygenated saltwater in the berm, they will be precipitated out by saline aggregation as well as metal oxide formation. The berm thus becomes a permanent trap for the contaminants keeping them contained and away from the immediate environment. This trapping mechanism is permanent so long as the oxygenated saltwater environment within the tidally active portion of the berm is maintained.

Evidence for the existence of this trapping process can be demonstrated using the additional monitoring data collected during CTM-12 (Appendix C) for iron, which is by far the metal in highest concentration within the fill. This data shows that the reduced ferrous iron (Fe^{+2}) is present in the dredged material fill wells at levels of up to 13 mg/L and is not detected (< 0.04 mg/L) in the berm wells. The more soluble ferrous iron within the fill is oxidized to ferric iron (Fe^{+3}) very near the berm\fill interface and is precipitated out of solution as insoluble ferric oxides and hydroxides (oxyhydroxides). The precipitating ferric oxyhydroxides are captured on the surface of the berm material and remain there. In fact total raw iron (unfiltered) has been detected in only 4 out of 31 measurements in water from the south berm wells at an average concentration of only 0.05 mg/L. The precipitating ferric oxyhydroxides will simultaneously coprecipitate other metals along with the iron. Coprecipitation with iron is a well known and highly efficient removal mechanism for trace metals from solution (Francis and Dodge, 1990). Once formed, the precipitated metal oxyhydroxides also act as a highly efficient surface-active sorption substrate for capturing additional metals from solution over time.

The berm also plays an equally significant role in controlling and limiting the organic contaminant concentration, both through enhanced aerobic biodegradation and precipitation via enmeshment in the ferric oxyhydroxide precipitates (Edzwald et al., 1974; Hahn and Stumm, 1970). Within the tidally active portions of the berm, dispersion and tidal mixing with oxygenated seawater create an environment which enhances the biodegradation of organic compounds. Biodegradation rates are much higher under oxygenated (aerobic) conditions versus anaerobic conditions as are present in the contaminated dredge material fill. Evidence of biological activity within the berm can be seen in the monitoring data from the CTM-10 and CTM-12 surveys (Appendix C) which show reduced oxygen and nitrate concentrations indicating oxidation of organic carbon is occurring within the berm.

Enmeshment and precipitation of organic contaminants occurs due to the strong complexes formed between ferric iron (and other trivalent metals) and the dissolved and colloidal organic matter (Jackson and Schindler, 1975; Preston and Riley, 1982). As ferric iron precipitates as oxyhydroxides, it will enmesh the complexed organic matter along with it. Any organic contaminants associated with the complexed organic matter will also be enmeshed in the process. This ferric oxyhydroxide-organic complex precipitate will also serve as a sorption site for further organic contaminant sorption due to equilibrium partitioning.

The evidence from the monitoring data suggests that enmeshment and biodegradation are effective at limiting the organic contaminant concentrations within the berm. The fact that no organic compounds were detected in the berm crest wells even though organic contaminants were found in the fill, is strong evidence that biodegradation and enmeshment are very effective at reducing their concentration within the berm.

Computer analysis indicates that the Short Fill could be more effective at containment if the saturated zone above the contaminated dredge material fill consisted entirely of low-permeability (uncontaminated) cap material. The Short Fill facility has a high permeability sand and gravel cap over the dredge material fill which, according to the computer modeling, allows rapid horizontal tidal flow into and out of the berm and some less rapid vertical flow into and out of the southern portion of the fill. This could potentially act as a transport channel for contaminants mobilized from the fill and/or the cap material. The model also indicates that the cap should hasten the inflow of fresh water from the North Pond into the fill, although chemical data to support this conclusion are not available at this time.

Chemical data from wells finished in the saturated zone of the structural cap material near the cap-dredge material fill interface support this conclusion, that the permeability of the saturated portion of the cap should be kept low. Well W-5A (finished just above the fill in the high permeability cap) showed the highest raw (unfiltered) metal concentrations of any of the thirteen wells sampled. A study designed to determine the cause of the elevated metals concentrations was conducted (Appendix E). The conclusion was that the elevated raw metals concentrations were the result of *in situ* release into suspension of metal-rich fine particulate cap material under reducing pore water conditions within the cap. This process was unrelated to any interaction with the fill.

A two layer cap system using a clean, high-permeability structural fill upper cap separated by a geomembrane from a lower-permeability clean structural material in the saturated zone above the contaminated dredge material would likely reduce potential metal mobilization and result in a lower metals discharge rate from the clean fill cap.

Computer sensitivity analyses indicate infiltration rate related to cap material plays only a minor role in limiting total flow from the system. The effects of infiltration on metal mobilization could not be assessed, however. It is possible that infiltrated rainwater could aid in mobilizing metals and is therefore likely to be an important feature of the facility. In this respect, the asphalt cover plays a dual role: 1) removal of precipitation before it can infiltrate and 2) as a working surface for terminal use.

The final process occurring within the outer portions of the berm is the dispersion and mixing with ambient seawater, resulting in a lower concentration discharge reaching the berm face. In conclusion, the major processes acting to effectively contain the contaminants were found to be precipitation, immobilization, and biodegradation.

X.1.b Environmental protection

The Short Fill has proven to be environmentally protective. It limits the release of contaminants to levels that are below CTMRAP performance criteria. Data collected over the past five years indicate no detectible organic contaminants being released. Biological testing shows no adverse impacts related the Short Fill. The Phase II modelling predicts that concentrations will remain within the standards over the 100-year period of analysis.

The Short Fill also appears to have helped reduce background concentrations levels in the 90/91 slip. Background levels for chromium and silver measured in 1985 are greater than those measured recently, as shown in Table 6.

Table 6 - Comparison of 1985 and 90/91 Slip Background Data

<u>Sample Period</u>	<u>Chromium</u>	<u>Silver</u>
May 1985	22.2 ug/l	2.2 ug/L
CTM Surveys	< 1 ug/l	< 1 ug/L

(Other contaminants are not listed as they were not measured in the 1985 background sampling survey).

The higher background values in 1985 may have been the result of industrial contamination released from sediments in the existing 90/91 slip. The Short Fill now covers or contains these materials along with the dredge fill. This containment isolates the now buried contamination that would otherwise discharge to the 90/91 slip through groundwater flow. Previous data from the 90/91 slip shows that the highest levels of contamination in bottom sediments were at the head of the 90/91 slip now occupied by the Short Fill.

X.1.c Overall evaluation of the model

The model gives reasonable predictions of the outflow rates and approximate concentration of contaminants discharging from the Short Fill. The output of the model is viewed as environmentally conservative since the model predictions of contaminant concentration are greater than the levels that actually occur. Thus, model predictions are not exact. Rather, they are conservative estimations (i.e. tending toward over estimation) based on the simplifying assumptions used in constructing the model making it more practical to use.

The use of conservative, simplifying assumptions to model the Short Fill is reasonable. Even with these conservative assumptions, the predicted performance of the Short Fill would meet the CTMRAP criteria for the 100 year prediction period.

The hydrodynamic portion of the model gives insight into the nature of flow in the berm-fill system. It indicates: areas where flow is highest, directions of flow throughout the tidal cycle, and preferred locations for monitoring wells. It also indicates the relative rates (velocities) of tidal inflow and rates of discharge from the fill through the berm into the 90/91 slip. Comparing these rates gives a ratio of the theoretical maximum dilution of the fill water at the berm face.

Hydraulic sensitivity analyses¹ performed on the model generated valuable insight into the preferred construction and operation of the facility. They indicate that fill permeability controls the net outflow far more than berm permeability. Therefore fill permeability will control the long-term net rate of contaminant discharge. Lower permeability berms would not significantly improve the performance of the system in terms of net outflow. As long as berm permeability is greater than fill permeability, discharge rates are controlled by the fill. However, berm permeability does have a direct effect on the dispersion within the berm which directly affects the dilution of contaminant concentrations.

Sensitivity analyses indicated the height of the North Pond also controls the net rate contaminant discharge from the Short Fill. Therefore the system is sensitive to the relative height of groundwater behind the system. In the case of the Short Fill, raising the water level in the North Pond produces greater net contaminant discharge from the fill, while lowering it reduces discharge.

The sensitivity analyses also demonstrated that several hydraulic factors had little impact on flow rates from the system. These factors included: rate of infiltrated precipitation, and storage coefficients² of the fill and berm.

The model used in this project was appropriate. It correctly predicted that the Short Fill facility was unlikely to exceed the CTMRAP performance criteria. However, for future projects, a more detailed and accurate model may be needed where application of the existing model indicates that the performance criteria would not be met. In this case, the existing model's predicted failure to meet the criteria could either be the result of

¹ A sensitivity analysis consists of a series of model runs where one parameter (for example hydraulic conductivity of the fill) is changed while the others are held constant. The model results from the series of runs are compared. Parameter changes that produce relatively large changes in output indicate that the model is sensitive to values of that parameter. Parameter changes that produce relatively small changes in output indicate that the model is not sensitive to values of that parameter.

² The storage coefficient is a hydraulic parameter that indicates the amount of water released by a material when it is subjected to a unit change of hydraulic head. A large storage coefficient indicates that a relatively large volume of water is released when the head changes (such as when the tide level drops).

the conservative simplifying assumptions used in constructing the existing model, or because the proposed facility actually could not effectively contain the contaminants as designed. The proposed facility may in fact meet the performance criteria but the overly-conservative model output may not accurately predict the actual concentration levels likely to occur. Improved model predictions would be needed to more accurately determine which of these situations were correct.

Model predictions could be improved by:

- Upgrading the model to a fully dynamic integrated hydrodynamics and transport model to directly include tidal action effects on transport;
- Inclusion of biogeochemical processes that control metal and organic compound concentrations; and
- By adding a dynamic boundary condition to the transport portion of the analysis to better assess mixing at the berm face.

These additions would require a more complicated integrated flow-transport model as opposed to the more simplified model used for the Short Fill project. An integrated model would be far more expensive to produce and run. It would, however, help differentiate between predictions of unacceptable concentrations resulting from overly conservative simplifying modeling assumptions, and predictions that more realistically represent actual system performance.

X.1.d Monitoring

Recognition of environmental concern and regulatory interest suggests that some level of monitoring may always be required at a near-shore containment facility. Model analysis and data collected to date indicate that less monitoring would be appropriate for the Short Fill facility. Sampling all wells on a quarterly basis does not appear to significantly improve the longer-term performance assessment. A more streamlined approach would be more reasonable following dewatering, as average concentrations are predicted to change over the time-scale of years, rather than months.

Much of the information collected to date has helped to better understand the processes operating within the facility. For example, the monitoring during dewatering was very helpful in determining the source of higher metal concentrations seen in the berms during this period. In particular, the short-interval tidal cycle monitoring in the active portions of the berm and the berm face were very helpful. However, only a portion of these data may actually be needed for performance monitoring.

Measurements along the most rapid and chemically active flow path are needed to assess compliance with CTMRAP. This flow path was defined by the modeling study as the tidally active zone near sea level, within the south berm. More than a single well in an alignment along the active flow path in the berm would have been more helpful in

determining the dilution and dispersion characteristics of the berm. However, sampling at these and other points in the system may only be necessary to provide better insight into operation of the system.

Monitoring samples should be analyzed and reported at levels which are below the levels for the fixed performance criteria such as EPA chronic saltwater criteria. This was a problem which arose in interpreting the mercury data from the Short Fill.

X.1.e Berm-face mixing

The initial mixing and dilution at the berm face reduces the concentration of contaminants reaching the 90/91 slip, thus reducing the impact on the waters in the 90/91 slip. Modeling analysis indicate that the dilution of contaminants leaving the fill could be up to 100:1 with water from the berm face. This dilution, or mixing ratio of 100:1 is based on modeling predictions of net flows out of the fill and tidal flows into the berm. The large ratio results because the high permeability berm allows sea water inflow at rates that are 100 times higher than the discharge allowed by the low permeability dredge fill.

The 100:1 mixing ratio is an average, theoretical maximum. It assumes that all of the discharge water from the fill completely mixes with the water flowing into the berm during each tidal exchange. In reality, mixing and dilution within the berms is a non-linear, time-varying, non-homogeneous dynamic process. The theoretical maximum which assumes constant homogeneous mixing does not occur. Thus, the actual average mixing or dilution at the berm face will be less than the 100:1 theoretical ratio.

This is confirmed by the monitoring data used in evaluating the performance criteria, which indicated a mixing ratio of somewhat greater than 5:1 between the middle of the south berm and the berm face. This ratio is much less than the theoretical maximum mixing ratio in part because it represents only that portion of the overall dilution which occurs from the berm crest outward to the berm face. An additional significant portion of the overall dilution occurs nearer the berm-dredge material fill interface before it reaches the middle of the berm.

Since sampling points were not ideally located to determine dilution, it is not possible to assess the actual average mixing ratio for the Short Fill. However, it is likely to lie somewhere between the 100:1 maximum theoretical ratio and 5:1. An estimate may be obtained from the CTM-7 25-hr tidal survey data assuming total organic carbon (TOC) acts as a conservative tracer as described in the Phase II modeling report. Average TOC concentrations in the contaminated dredge material fill are about 36 mg/L while concentrations in the center of the berm range from 2 to 5 mg/L with the 90/91 slip water concentration at about 1.7 mg/L. Assuming 90/91 slip water mixes with fill water to produce the berm TOC concentration, the calculation yields an overall dilution between the fill and the berm face in the range of from about 8:1 to 35:1. As expected, this range is significantly less than the 100:1 theoretical maximum.

X.1.f Inflow from upland areas and other interactions

Groundwater inflow from the upland area directly north of the site is probably somewhat restricted by the timber and concrete bulkhead which encloses the Short Fill site.

However, pond levels do show seasonal changes coincident with the upland groundwater. The monitoring data from the upland well W-10 (Figure 2) has shown elevated levels of organic contaminants including benzene, ethylbenzene, toluene, and xylenes (BETX); low molecular weight polycyclic aromatic hydrocarbons; chlorinated hydrocarbons; phenols; and phthalates throughout the surveys. These same contaminants, with the exception of the chlorinated hydrocarbons, were detected in the North Pond at stations 11s and 11d during CTM 2 (12/12/86) and CTM 4 (5/12/87) but at generally much lower concentrations. The deep North Pond station (11d) was also usually higher concentration than the shallow station (11s). These compounds were not measured above the detection limit during the later surveys (CTM 6 and 11).

The only compound measured above the detection limit in the north berm wells (W-7A, 7B, and 7C) without laboratory blank contamination was bis(2-ethylhexyl)phthalate. It was also measured occasionally in the other wells and in the background 90/91 slip water and is possibly related to random sample contamination during collection. Therefore it appears that there probably is some contamination of the North Pond from the upland groundwater which may be diminishing over time. The north berms have not picked up any of the contamination from the North Pond, and the fill is not impacting the North Pond water quality.

The overall long-term effects of groundwater flowing into the Short Fill from the upland areas (via the North Pond) are not known at this time. However, it is likely that as the fill pore water becomes fresh, some colloidal stabilization and release of contaminants from the solid phase into solution may occur. These colloids would be de-stabilized and precipitated out upon reaching the berm (see Section X.1.a and Appendix F).

Monitoring data show that calcium and strontium concentrations (indicators of sea water³) have steadily decreased over time in the North Pond and also within the north berm at the Well 7 site, indicating the transition from salt to freshwater. A recent hydrography survey during July 1992 confirmed that the North Pond had turned fresh by this time. Concentrations of most metals in the two deepest north berm wells, W-7B and W-7C, have also decreased over time. This evidence was used to help develop the working hypothesis in section VIII that the more reducing, organic-rich saltwater from the dredge material fill, which entered the north berm during dewatering, was responsible for the initial leaching of metals from the berm material. There is no evidence at this time to suggest that the freshwater has as yet entered the fill through the north berm.

³ Salinity was not measured. Strontium and calcium can be used as a general indicator of salinity when chloride or conductivity data are not available.

Other areas of the Short Fill which should receive inflow from the upland areas include the cap which is highly permeable and in direct hydraulic contact with the north berm. Water level and model analysis of the site indicate that freshwater will flow from the North Pond through the upper regions of the saturated zone in the cap toward well W-5A. This water should have reached well W-5A in about 250 days following cap placement (Appendix F). Calcium and strontium data for the cap well W-5A are consistently somewhat lower than the north berm wells suggesting that fresher water may have ponded in the cap at W-5A during cap construction.

The monitoring data showed that there may have been an interaction of the fill with the cap material influencing the chemistry in the upper portions of the Short Fill. The monitoring data show metal concentrations in the cap pore water (well W-5A) which are considerably higher than in the fill or berms. The CTM 13 cap chemistry survey was designed to test hypotheses related to fill/cap interactions which might give rise to higher concentrations in the cap pore water. The results of the survey support the hypothesis that the elevated raw metals concentrations from well W-5A are the result of the *in-situ* release into suspension of metal-rich fine particulate cap material under reducing pore water conditions within the cap. Neither of the hypotheses which invoke either tidally induced vertical transport or the bubble transport from the fill were supported by the data. Introduction of saltwater from the fill into the cap and corrosive release from the cap materials as seen in the berms (see Section XIII.1) did not occur in the cap as evidenced by the calcium and strontium data described above. Consequently, this evidence rules out any direct long-term influence of the dredged material fill on the cap chemistry for the Terminal 91 Short Fill.

X.2 APPLICATION TO OTHER SITES

X.2.a Scaling to other projects

Construction of larger and smaller containment facilities appear feasible based on the assessment of the performance and operation of the Short Fill project. Different sized facilities will likely produce different hydraulic gradients and therefore different contaminant concentrations and volumes.

The performance of each new project will depend on its site specific situation. A site- and design-specific analysis may be needed to quantify the expected performance of each new facility. Nevertheless, insight into the general behavior of different sized facilities has been gained from the Short Fill project. The discussions below compare hypothetical facilities that are similar to the Short Fill, but with one part of the system changed (such as size or the degree of contamination of the dredge materials). Since an infinite range of possible variations on the Short Fill design are possible, only a few examples which span the possible range are discussed.

This discussion will focus on the more mobile and persistent metal contaminants. Fortunately, organic contaminants which are more persistent are also generally much less mobile, and the more mobile organics are also much less persistent. Therefore, as evidenced by the Short Fill monitoring data, moderate amounts of organic contaminants

in the contaminated dredge material are less likely to affect the performance of the containment system than are the metals. Considering all of the factors which can affect the performance of the system, it should be kept in mind that the following discussion serves only as a general guideline to likely performance.

Larger facilities with longer berms and more berm area containing greater volumes of contaminated dredge material are obviously more likely to produce a proportionately greater total mass of contamination leaving the facility. However, the percentage loss and concentrations at the berm face would not necessarily increase in a larger facility. A larger facility is likely to have a longer berm face which allows more total discharge of water from the system. The greater width of the berm in a larger facility would also create a larger volume for mixing and dilution within the berm. Both of these factors would tend to lower the concentrations of contaminants reaching the berm face. Therefore, if performance standards are based on concentrations at the berm face, then a larger facility may be acceptable even though the larger facility may discharge a greater total mass of contaminants.

Under some special circumstances, the greater mass of contaminants leaving a larger facility could possibly cause the accumulation of higher concentrations of contaminants near the facility than those caused by a similar, but smaller facility. Circumstances which might contribute to accumulation of contaminants would, for example, depend on the local mixing and circulation of waters near the facility. Obviously, if more contaminant mass was being released into the finite volume of a small embayment which was not well flushed, in a pristine area with no other contaminant sources, the contaminant loss from the facility may potentially be detectable. If performance criteria were based on comparison of near-facility contaminant levels with pristine background levels, a more conservative design for the larger facility may be needed to meet the criteria.

Smaller facilities (with correspondingly smaller berms that are shallower and/or thinner) will also have a reduced mixing and dispersion zone within the berms. The reduced capacity for mixing and dispersion may lead to higher concentrations of contaminants discharging from the system. If standards are based on concentration levels of the discharge water at the berm face, a smaller facility with a thinner or shallower berm may not be acceptable. A more conservative design (e.g. a wider berm) for a smaller facility may be needed in some situations to meet the criteria.

For smaller facilities, the total mass of contamination reaching the receiving water may be less. The smaller facility, having less total contaminant mass, will ultimately discharge a smaller mass of contaminants. If performance criteria are based on comparison of contaminant levels near the facility with background levels away from the facility, the lower discharge volumes may produce acceptable concentrations near the smaller facility.

X.2.b Permeable side berms

In general, side berms with permeabilities approaching that of the end berms allow a larger area through which water discharges. If everything else is comparable, permeable side berms will increase the flow rate into the receiving waters. The concentration of the

discharge would either be similar to a system without permeable side berms or possibly lower. Therefore the rate of release (concentration times flow) could either be greater or about the same as from a system without permeable side berms. If the facility is located in an pristine area with no other contaminant sources with restricted circulation and poor flushing, the potential increased rate of contaminant release may possibly result in contaminant accumulation and measurable concentrations in the near-facility environment. Depending on the design of the system, permeable side berms which encompass a very large facility may still maintain a relatively low berm area to total contaminant ratio and therefore limit the relative percent loss over time.

Permeable side berms may also reduce groundwater gradients pushing water through the system and thereby be beneficial. Smaller gradients would produce a smaller volume of contaminant discharge. A site- and design-specific analysis would be needed to assess the overall effects of berms on groundwater levels and overall discharge rates and concentrations.

X.2.c Dredge materials with higher contaminant concentrations

The Short Fill project results suggest that a similar facility could be constructed with dredge material with contaminant concentrations higher than those used and still meet the CTMRAP standards. The predicted concentrations discharging from the system would be more likely to be close to the CTMRAP standards, however. Such a facility may lead regulatory authorities to require a more accurate predictive analysis in order to assess whether the facility is likely to meet the standards.

Containment of dredge materials with high contaminant concentration would likely require a detailed analysis of the interstitial water of the prospective material. The Short Fill project initially used data from bulk chemistry analysis and estimated interstitial water concentrations from materials believed to be representative of the sediments likely to be used in the facility. The actual concentrations in the as-built facility were considerably lower in some cases (especially for metals) than those originally anticipated. This indicates that bulk chemistry is generally not a good predictor of interstitial concentrations for metal contaminants, and that actual interstitial water measurements are needed.

X.2.d Design improvements

Four design factors were found to be most important in increasing the environmental protection of the Short Fill containment facility:

- Lower permeability for the dredge fill;
- Higher permeability for the berm;
- Limiting net flow through the system by lowering groundwater levels (represented by pond height); and
- Low permeability sediments throughout the entire saturated zone above the fill.

In addition, an oversight that occurred during construction of the Short Fill should be avoided in future projects. Each of these factors, including the oversight are discussed below.

Lower permeability of the fill would reduce the overall rate of contaminant flow from the system. Mixing low permeability sediments with the dredge fill (or using contaminated dredge material with a higher clay content) would result in fewer contaminants reaching the immediate environment. The reduction would occur in both concentration and total volume flowing into the receiving waters.

Higher permeability in the berm would reduce the concentration of contaminants discharging from the berm. The higher permeability would produce greater tidal mixing that would reduce concentration by dilution. However, assuming the efficiency of trapping metals within the berm remains the same, the total mass of contaminants discharging into the receiving waters would remain the same. This would imply that leach rates from the contaminated fill would increase slightly. Performance criteria based on comparison of near-berm water concentrations with background water concentrations could still be violated, if contamination accumulated nearby. Only concentrations discharging directly from the system would be reduced.

Low permeability fill throughout the entire saturated zone above the dredge fill would improve performance. The current situation with a saturated high permeability zone above the dredge fill allows some tidal exchange in the southern portion of dredge material fill and possibly the introduction of oxygenated water to mobilize metals. A two layer cap system using a clean, high-permeability structural fill upper cap separated by a geomembrane from a lower-permeability clean structural material in the saturated zone above the contaminated dredge material would likely reduce the chance of metal mobilization and result in lower contamination discharge rates from the system. Keeping contaminated dredge fill below an elevation of 0 mean lower low water would also likely reduce contaminant discharge (especially metals).

Lowering the upgradient groundwater level and thus reducing flow into the system would generally reduce both concentrations and total quantity of contaminants discharged from the system. A gradient control system such as a french drain or well system may improve system performance by reducing the flow gradient throughout the system. Lowering groundwater levels could be problematic as the upgradient groundwater flowing into the system may also contain contaminants. Pumping the groundwater and subsequent discharge or treatment of the contaminated water may produce regulatory problems and add additional costs.

As mentioned above, an oversight occurred during construction of the Short Fill that should be avoided in future projects. A contractor working on a different project end-dumped clean sand and gravel from an adjacent upland beach excavation on top of the dredge fill along Pier 91. This created a "mud wave" that placed contaminated fill at an elevation of up to +7 feet along a portion of the west boundary of the site. The general fill height after all of the dredge material was in place during the capping contract negotiations had been about +1 foot. Although no direct evidence indicates the mud

wave produces more contaminant discharge than a horizontal interface, theory suggests that this area could allow metal mobilization if the upper portion becomes alternatively saturated and unsaturated in the tidally active southern sections of the fill. Placing and spreading this material with a method that maintains the generally flat surface of the dredge materials is recommended.

X.2.e Parameters to measure

X.2.e.1 Hydraulic parameters - Measurement of several parameters critical to operation of a containment facility are recommended based on the experience with the Short Fill. These parameters are necessary to understand flow, chemical transport and reactions that occur within the system.

The measured parameters needed to predict hydraulic flow include:

- Hydraulic conductivity of the fill, and
- Hydraulic conductivity of the berm.

These parameters are best measured in the field after the facility is constructed. The Short Fill experience showed that representative laboratory measurements are often difficult to obtain because true field conditions cannot be entirely replicated in the lab.

The parameters needed to understand transport include:

- Total porosity,
- Effective porosity, and
- Dispersivity of the berm.

Total and effective porosity should be measured on "undisturbed" samples from the fill and berm. The total porosity measurements in the dredge material fill samples are needed to assess the total amount of contaminants within the facility which are either part of the fluid voids or the solids. The dissolved and colloidal material in the fluid voids is obviously subject to transport through the system. Effective porosity measurements for the fill and berm are needed to assess the fraction of the total fluid voids which are involved in the direct transport of the fluid through the fill and berm. That is, some of the voids are dead end pockets and do not participate in the fluid transport through the system.

Dispersivity within the berm is needed to predict both the dispersion and dilution, and the transport of contaminants through the berm. It is often estimated using existing studies because field and laboratory measurements are costly and are usually difficult to set up. Scaling is always a consideration, and it is often necessary to scale up from small-scale laboratory measurements which are typically several orders of magnitude less than those measured in the field for similar materials.

In the field, dispersivity would be especially difficult to measure within a berm with a configuration such as that of the Short Fill (as discussed in Hart Crowser, 1988 and PGG/CCNW, 1990). The main problem would be the interpretation of the data since there is no precedent for interpreting the field measurement of this parameter in a tidal environment. Interpretation would be difficult primarily due to the complex tidally-influenced boundary condition associated with the system. An integrated hydrodynamics and transport model with time-varying boundary conditions would probably be required to interpret the field results. If future field techniques and interpretive modeling become available to measure this parameter, its measurement is recommended for future projects.

It may be possible to estimate dispersivity using natural quasi-conservative tracers present in the berm such as total organic carbon and total inorganic nitrogen as was done in the Phase II modeling for the Short Fill. Numerous wells along the flow path within the berm would be needed along with a number of concentration measurements over time.

X.2.e.2 Chemical parameters and other measurements - Several dissolved metal concentrations should be measured to determine contaminant levels in the contaminated dredge material fill and potential reactions that may occur which would control their concentration. Based on concentrations in the bulk sediment and interstitial waters, selected highly mobile metals such as copper, nickel, and zinc are recommended along with their associated matrix metals iron, and manganese. Other metals of concern such as mercury, lead, and cadmium should also be considered. Barium is also recommended as it may act as an indicator since it co-varies with manganese.

Organic contaminants should also be measured in the bulk sediments to be dredged. The equilibrium partitioning approach appears to work well for predicting soluble organic concentrations from bulk chemical concentrations. If any soluble concentrations of organic compounds are found at levels of concern, their inclusion in any monitoring may be appropriate. However, the Short Fill experience shows that none of the organic compounds detected in the fill water were detected in the berm.

Several parameters should be measured to help understand redox dynamics within the system. These include dissolved oxygen, sulfate/sulfide, ferrous/total iron, dissolved inorganic nitrogen species and possibly methane. Salinity and/or conductivity should also be measured to understand the movement of freshwater through the system as its introduction is likely to cause chemical reactions, such as oxidation (and mobilization) of metals.

Total organic carbon and total inorganic nitrogen appear useful as natural tracers within the system. The former is believed to be more conservative and is recommended if only one is measured.

One or two sets of water levels during a 25-hour tidal cycle measurements should be made to evaluate when the low and high water levels occur in the containment facility in relationship to higher-high and lower-low tide. The time lag can then be used to select

periods to obtain samples representing highest concentrations (lower-low water), average concentrations (a period intermediate between higher-high and lower-low water) and lowest concentrations (higher-high water). Additional sets of tidal cycle measurements are also needed to calibrated a model, if needed as part of the evaluation of the facility.

X.2.f Applicability of the Short Fill model to other sites

The results of the model constructed and calibrated for the Short Fill can be directly applied to other sites, if conditions are similar. Similar conditions are defined as:

- Fill contaminant pore water concentrations not more than two times greater than those at the Short Fill;
- Berm and fill materials with hydraulic conductivities between one half to twice those of the Short Fill;
- Groundwater levels behind the fill (upgradient) within one foot of those at the Short Fill;
- Side-berm permeabilities no more than one order of magnitude larger than those at the Short Fill;
- Fill entirely within the saturated saline environment; and
- Berm width along the flow path within 20 percent of Short Fill.

Facilities outside of these requirements will likely need a site and design specific analysis that may include a calibrated model. The existing Short Fill model may be modified for evaluation of a new facility if it is similar to the Short Fill. In this case calibration data will need to be collected after it is constructed, to help verify the predictions made by the model. A significantly different site and/or design from the Short Fill may require a new model.

Even where the Short Fill model results cannot be directly applied, the insight gained from the sensitivity analysis can be indirectly applied to other sites. Parameters significant in the Short Fill model will likely be significant in other near-shore containment projects. These parameters include:

- Hydraulic conductivity of the fill;
- Effective porosity of the berm and fill;
- Dispersivity and width of the berm;
- Groundwater levels upgradient from the facility; and
- Initial contaminant concentrations within the fill pore water.

X.2.g Other factors not assessed

Several factors that may, in the future, affect the flow of contaminants from the Short Fill facility were not assessed as part of the project. These include: freshwater intrusion, sea level changes resulting from global warming, and unexpected changes in the facility or the areas upgradient from the Short Fill site.

Freshwater flowing from the North Pond into the fill may release metals and colloids containing contaminants from the sediments in the fill. This could occur anywhere in the Short Fill where solutions with significantly different oxidizing potentials (such as the more oxidizing freshwater from the pond and the reducing water in the fill) interact or where the fill changes from saltwater to freshwater. However, once the fill water reaches the oxygenated saltwater in the berm, the colloids and metals will be precipitated out by saline aggregation as well as metal oxide formation. This trapping mechanism is permanent so long as the oxygenated saltwater environment within the tidally active portion of the berm is maintained.

Indirect salinity data (calcium and strontium) for wells at the W-7 site and water in the North Pond suggest that freshwater intrusion has started within the north berm. However, no evidence yet exists that freshwater intrusion has reached the fill, so that the effects of freshwater intrusion within the fill have not been confirmed by measurement.

The long-term effects of global warming and sea level rise on the system were not addressed. Current estimates of sea level rise range from a few inches to several feet or more during the next 100 years. Locally, sea level trends in Seattle have been increasing at an average rate of about 2 mm/yr over the past 90 years (Canning, 1990). The overall effects of sea level change have not been evaluated.

Other factors not yet recognized may affect the facility. These factors include changes in the upland region lying upgradient from the facility discharging groundwater to the site, or the facility itself. Evaluation of any such effects can only occur if and when they are identified.

SECTION XI

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APPENDIX SUMMARIES

The following are summaries of the the appendices to the Terminal 91 Short Fill Monitoring Project Report. Each summary contains a description of the work and/or report presented in that appendix. These summaries also contain some of the same information and conclusions presented in the Final Project Report to tie them together.

Appendix A.1 - Hydraulic and Contaminant Modeling, Terminal 91, Seattle, Washington

This report describes a hydraulic and transport model used to estimate the behavior of the T-91 short fill before it was constructed. The hydraulic portion of the model consisted of a two-dimensional, vertically oriented, finite element transient analysis using: a 214 element grid, varying boundary conditions to simulate tidal action, a variety of construction options (different permeabilities, pond levels, capping materials, etc) and a sensitivity analysis to evaluate what parameters played a major role in assessing the hydraulic responses of the facility over time. The hydraulic responses were then used as input for a one dimensional analytic transport model to simulate the transport of various chemical species. Input parameters for the models were estimated from the literature with some laboratory tests on materials expected to be used in construction. Chemical concentrations used as input to the model were based on analyses of samples of sediments expected to be placed in the structure. The models were run to select the preferred construction and management options and to estimate contamination released over 100 years.

Highlights of important information include:

- A predictive model was developed to assess construction options and environmental response of a proposed "short-fill" facility to be constructed as part of the new Terminal 91. (pp 1-5)
- The results of the models indicated that facility was unlikely to produce deleterious contamination to the waters of Smith Cove. The preferred construction option was to build the facility with the pond remaining at its "natural" level during dewatering. The model also indicated that the permeability of materials placed above the dredge materials was not significant during dewatering. (pp 5-7)
- The general approach for the project was to develop two independent models: one for hydraulic response of the system and one for transport through the berm. A combined hydraulic-transport model would require too much computer time to simulate 100 years of operation with eight or more daily tidal variations as input. (pp 9-10)
- The hydraulic model consisted of a two-dimensional, vertically oriented ("slice"), finite element model (with 214 elements) based on FPM (developed by Golder and Associates). (pp 11-12)
- Input consisted of estimations of hydraulic values resulting from expected construction conditions and options, a variety of boundary conditions to simulate pond heights, infiltration, tidal action etc., and limited laboratory measurements of hydraulic conductivities of proposed berm materials. (pp 13-14)

- A sensitivity analysis indicated that the factors having the greatest influence on contamination release included: dispersivity of the berm materials, hydraulic conductivity of the dredge fill materials, and pond elevation. (pp 15-17)
- The hydraulic model produced heads and velocities that served as input to the transport model. In addition, a comparison of tidal inflow/outflow velocities with advective flow originating from the fill indicated that mixing at the berm face could be as great as 100:1 or more. (pp 16-22)
- The transport model consisted of a steady-state, one-dimensional analytical model based on ODAST (developed by Javandahl, et al). The modified model (LEACH) used estimated values of the dispersion coefficient (based on the flow velocities generated by tidal action and dispersivities from the literature. Other input parameters were estimated from analyses of local materials representative of those planned for the facility. (pp 23-27).
- The model was run using various construction options, values of dispersion coefficient, and selected contaminants. The results indicated that relatively minor contamination levels would be generated if dispersivities were high ($10 \text{ m}^2/\text{day}$). Concentrations of some contaminants (cadmium and mercury) might exceed existing standards if the dispersivity was low ($0.1 \text{ m}^2/\text{day}$). (pp 28-31)
- Several construction and monitoring recommendations are given. (pp 29-39)

Appendix A.2 - Criteria, Threshold, Monitoring and Remedial Action Plan

This appendix contains a copy and an overview of the Criteria, Threshold, Monitoring and Remedial Action Plan (the Plan or CTMRAP). The Plan was originally submitted as part of the Water Quality Certification for the Terminal 30 Expansion Project 404 dredge and fill permit.

Plan Purpose and Overview

In 1984, when the Terminal 91 Short Fill was first proposed, the regulatory agencies believed that the Port lacked sufficient field data on long-term contaminant mobility from tidally-influenced near shore disposal sites to fully appraise the project. A series of meetings between the Port and the agencies ensued to discuss ideas and approaches for resolving the issue. Major agency input during these discussions came from EPA Region 10, the state Department of Ecology, and the U.S. Army Corps of Engineers.

The primary agency concerns which surfaced during these discussions were how to reasonably predict, monitor, and potentially remedy, to the agencies satisfaction, the performance of the disposal site. As a first step, the Port needed to assure the agencies that the containment system would provide adequate environmental protection based on existing water quality criteria. In order to evaluate the potential level of environmental protection the facility would provide, the agencies requested a reasonable prediction of the percent loss of the total amount of contaminant in the fill over time, and the potential impact on the surrounding marine waters.

To evaluate the projected performance of the Short Fill, the Port proposed a modeling study to predict the long-term contaminant mobility from the Short Fill. The report from that study, the Phase I modeling report (Appendix A), predicted that the Short Fill design would provide acceptable containment and would not likely produce concentrations at the berm face which exceeded chronic saltwater criteria. The modeling predictions were cautiously accepted by the regulatory agencies.

The Port's environmental section proceeded with the next step of the project which was the preparation of a plan to monitor the system's performance and to potentially remediate the system if it failed performance criteria agreed upon by the Port and the agencies. To verify that the Short Fill system would perform as predicted, and to have a plan to remediate the system if it did not, the Criteria, Threshold, Monitoring and Remedial Action Plan was created.

The major purpose of the Plan was to:

- To establish the basic criteria against which performance of the disposal site would be measured;
- To detail a monitoring program for measuring performance and tracking the movement of contaminants at the site;

- To set threshold levels for initiation of remedial actions;
- To establish remedial actions that would be implemented if the system did not meet the performance criteria and should prove to be a long-term water quality problem;
- To provide research and modeling verification that would make the results more applicable to other dredged material disposal projects; and
- To establish a monitoring plan to insure the protection of local water quality during the filling operation.

Performance Criteria

The performance criteria were established in cooperation with the lead regulatory agencies: the Army Corps of Engineers, EPA Region 10, and the Washington State Department of Ecology. The existing 1985 EPA chronic marine water quality criteria were used. For contaminants for which no EPA accepted criteria existed, ten times background seawater concentration was established as the criterion. The background seawater values would be determined from samples collected in the slip between Terminals 90 and 91. Initially, five replicate samples were collected in May, 1985 to establish the mean and standard deviation of the background concentration. These values would be updated with the inclusion of the data from the monitoring program.

The discharge from the fill during consolidation and dewatering (first six months) was considered part of construction phase of the project. During this phase the discharge was categorized as an acceptable short-term impact within the dilution zone as established in the Water Quality Certification. However, the discharge would have to meet the EPA acute marine water quality criteria within the dilution zone. The dilution zone extended 100 meters south of the south crest of the south berm.

The post-construction point of compliance for chronic criteria was considered to be the long-term average (i.e. chronic) concentration at the berm face through which the major discharge was predicted. The most probable pathway and therefore the major point of compliance established was the south berm face in the slip between Terminals 90 and 91.

Action Thresholds

The action threshold levels are defined in the Plan as those levels in the monitoring wells which would indicate a high probability of exceeding chronic saltwater criteria at the berm face. Exceeding the action threshold would indicate a failure of the disposal site to adequately contain the contaminants. Exceeding the threshold values would justify initiating remedial action to contain the contaminants.

Two tiers of threshold levels were established:

1. Above the saltwater background values, and
2. Above EPA's chronic marine water quality criteria or above ten times the saltwater background value.

Exceeding either of the threshold levels would initiate notification of WDOE, EPA, and the Corps. The agencies would confer with the Port to determine:

- The potential environmental impact;
- The possible need for three additional confirming samples;
- If necessary, the appropriate dilution factors to be applied to the values determined from the wells; and
- The appropriate remedial actions required if both impact and levels were confirmed.

Determination of any potential environmental impact would rely upon the EPA list of "Lowest Reported Toxic Concentrations" for contaminants that have been shown to cause impacts on appropriate target species in the marine environment. The dilution factor would be established using the monitoring data from the wells in the center of south berm, the berm face wells just inside the berm face, and measurements of the surface seawater adjoining the berm face. It would be used to relate the well concentration to the probable concentration expected at the point of compliance (the berm face).

In practice, the first threshold level would be handled by notification and discussions of potential environmental impact. However, the agencies reserved the right to implement further action if it was determined that there was a potential impact from the contaminated dredge material. The second threshold level would trigger the same notification as the first level. However, a higher level of response would be considered.

Remedial Action Plan

According to the Plan, all remedial action decisions would be based on results from replicated sampling. The measured levels would have to be statistically greater than the threshold. Elevated levels would also have to be demonstrated to be from the contaminated dredged materials. Remedial actions would then be implemented in an incremental fashion. The increments include:

- Hold the upgradient water level in the pond at mean tide (+6.6 feet). This would eliminate the advective flow through the fill.
- Pump the interstitial water out of the fill and discharge to a Metro sewer (an interim measure). This would minimize water flow seaward through the south berm.

- Chemical stabilization if possible. This depends on the contaminant. This is a new technique and would be used only if new information showed it to be acceptable for the specific contaminant causing concern.
- Build a slurry wall the north and south berms.
- Build a slurry wall the east and west berms.
- Remove the contaminated dredged material from between the berms.

The appropriate initial increment would be chosen by mutual agreement between WDOE, EPA, the Army Corps, and the Port. A sampling and analysis program to determine the effectiveness of each increment would be implemented. Each step would be evaluated through sampling and analysis before a determination as to whether a further remedial action would be needed.

Monitoring Program

The results from the Phase I modeling report (Appendix A) were used to help determine monitoring well location and sampling depth. Well depths coincided with the hydraulically active upper layer in the inter-tidal zone, the shallowest layer of the fill below the inter-tidal zone, and the deeper fill layer. Ten well locations were initially chosen along with six water sampling stations. Three of the well locations were designed as nested groups of wells (three wells per group) for a proposed total of 16 sampling wells.

Well locations were chosen to best monitor the performance of the system in terms of hydraulic flow and contaminant concentrations. This information would be used to:

- Monitor for water quality violations based on the criteria and thresholds, and
- Verify the pre-project modeling and re-evaluate long range predications.

The Plan's schedule of monitoring activities included:

- Sampling after the dredged material was placed in the site and before it was surcharged with the clean fill cap.
- Monthly sampling for the first six months after the dredged material was in place and covered.
- Quarterly sampling for the following two years.
- Semi-annual sampling for the following two and one-half years.
- Special research-oriented sampling for low-level organics and close-interval sampling over a tidal cycle.

APPENDIX B - Short Fill Construction and Well System Installation

Following approval by Ecology and selection of a contractor, Short Fill construction began during the summer of 1986. The north berm was constructed first using barged-in sandy gravel placed through water with a barge-mounted drag line. The south berm was then constructed in a similar manner, but with a notch to facilitate placement of the dredge fill.

The majority of the dredge fill was placed by bottom dump barge. Because the Port expansion projects planned for this period did not proceed as planned, Corps of Engineers maintenance dredge materials unsuitable for open-water disposal were used to help fill the site. Even with this additional material, the top of the fill lay at an elevation of about +1 foot mllw as opposed to the +8 feet mllw originally planned.

The dredge fill lay open and uncapped for a period of about 6 months. During this time, the fill consolidated and the free standing water over the dredged material clarified as the dredged material fines settled out.

During the six-month delay, a small amount of clean beach material from the adjacent intertidal habitat reconstruction project, was placed in the fill. The beach material was pushed out along the west and northeast corner of the fill. This produced a small "mud wave" in front of the clean material creating an uneven surface along the west side of the fill. The remaining beach material was stockpiled on the north and south berms.

After the six-month consolidation period, the contractor pumped off the free standing water in preparation to placing the cap material over the fill. The remaining beach material and cap material were pushed out and dumped using specialized, small, light weight mud cats with front-end loaders, instead of the drag lines originally planned. This allowed the cap material to be spread evenly in layers over the fill, working outward from the berms.

Stockpiling of the beach and cap material on the berms precluded well installation immediately following berm construction. Well installation began in November of 1986. Details of the well and pump installation are given in the attached 1988 Hart Crowser report: Data Report, Monitoring Well Installation and Physical Characteristics of Berm-Fill Material, Terminal 91, Port of Seattle.

This report describes the installation of monitoring wells and pumps in the short fill, Pier 91 and upland area to the north. It also describes laboratory and field testing performed on the site. These tests calculated hydraulic properties of the berm and fill. A literature review of dispersivity coefficients was also presented.

Important information in the report includes:

- Fourteen wells were installed in the short fill, Pier 91 and upland to the north (pp 2-5). Thirteen of these wells had dedicated pumps for sampling (pp 5-7).

- Hydraulic conductivity tests were conducted in each of the finished wells (p 8) and in the laboratory on collected samples (p 9).
- Comparison of lab and field data indicate that field data appear to be more representative of site conditions (pp 9-11).
- Extrapolation of measured data to non-measured sites indicated the following representative values (pp 11-13):

Berms and top fill: 2×10^{-2} cm/sec
 Top fill/dredge fill mix: 4×10^{-4} cm/sec
 Dredge fill: 1×10^{-4} cm/sec
 Permeable zone in Pier 91: 6×10^{-3} cm/sec
 Piers 90 and 91 overall: 3×10^{-3} cm/sec
 Upland zones near MW-10: 5×10^{-4} cm/sec

- An updated literature review of representative values for dispersivity (pp 13-15) indicated that the values used in the Phase I model were probably too small. A more realistic and environmentally conservative range would be 1 to 10 meters.
- Review of the new data (pp 15-19) indicated that the estimated values for hydraulic parameters used in the Phase I model were generally correct.
- The report concluded (pp 19-20) that new information would not significantly effect the conclusions derived from the Phase I model. Its results would still be environmentally conservative.

Highlights of the well installation are described below.

The first set of monitoring wells were installed during late October, 1986, following placement of the cap. These wells included those on the berms (MW-2, MW-3, MW-4A, MW-4B, MW-4C, MW-7A, MW-7B, and MW-7C) Pier 91 (MW-9) and north of the site (MW-10). The second set of wells placed to monitor the fill area (MW-5A, MW-5B, MW-5C, MW-6) were installed during April, 1987. These wells could not be installed until the weight of the cap caused most of the consolidation in the fill to occur. Prior installation would have damaged these wells.

A third set of wells were originally planned along the face of the south berm. These wells were to have monitored contaminant concentrations just before they exited from the berm. Unfortunately 3,000+ gallons of bunker oil were spilled into the slip south of the berm just before the wells were installed. A portion of this oil washed onto the berm face allowing oil to penetrate to a depth of several feet. A portion of the south berm face was removed to reduce the oil storage in the berm. A small amount of oil remained and continued to ooze for several months. Because of the potential for masking true contaminant concentrations from the berm, the third set of wells was not installed. Another small oil

spill of unknown origin was observed in the slip several months later further complicating monitoring along the berm face. Berm face wells are now planned only if the need to quantify a specific contaminant is identified.

Each well consists of non-glued, 2-inch diameter, schedule 80 PVC casing completed with 5 to 10 feet of 0.020 slot screen. The well screens are surrounded by Colorado silica sand. The annulus above each screen was backfilled with a VOLCLAY™ bentonite slurry. The top of each well is covered by a locked steel monument cemented into place. Wells MW-7A, MW-7B and MW-7C are topped by flush mounted monuments to facilitate traffic.

All wells (except for MW-9) have dedicated WELL WIZARD™ pumps for sampling. The pumps consist of 1.7 in PVC bodies containing teflon™ bladders. The bladders are activated with air pumped through polyethylene lines. Samples are returned to the surface through teflon™ lined polyethylene hose.

Well MW-3 was accidentally damaged during 1986 by heavy equipment. The well casing was broken above the water table. No water appears to have entered the well although a small cobble has rolled into the well such that the pump cannot be removed. The break was repaired five feet below ground surface with a riveted section of PVC. The well still functions and is still in operation.

APPENDIX C - Monitoring Results

This appendix contains the tabulated results of the 13 monitoring and special surveys conducted as part of the Criteria, Thresholds, Monitoring and Remedial Action Plan. Table C-1 lists the survey, date, wells and stations sampled, the analyses conducted, and the purpose of the survey.

The following series of tables (Table C-2) give the results of the 13 surveys in chronological order. CTM 12 was conducted in February of 1991 as a follow up to CTM 11. The metals data from CTM 11 were reviewed and found to be inconsistent with the previous data. The cause was traced to a change in analytical methodology used by the laboratory. Most of the wells and stations were resampled and analyzed using the same methods as in previous surveys so that the data could be included without bias. CTM 13 was conducted to determine the cause of the anomalously high raw metals concentrations noted in well W-5A during the surveys.

All metals results except for CTM 13 are from the "raw" sample. The raw metals analysis uses a decanted aliquot from the sample container after the suspended solids have had time to settle (approximately 24 hours after receipt). The decanted samples are not filtered and are not preserved prior to analysis. Duplicate 100 mL aliquots of each decanted solution were extracted using a standard ammonium pyrrolidine dithiocarbamate / methyl isobutyl ketone (APDC/MIBK) technique. This procedure complexes the metals with the APDC and extracts them from the water sample into the organic solvent (MIBK), which are then analyzed by either direct aspiration into a Perkin Elmer Model #603 atomic absorption spectrograph (AAS) or a Perkin Elmer Model #306 AAS equipped with a heated graphite atomizer Model #400 furnace head and Model #2100 controller.

The CTM 13 survey included analysis for dissolved and total metals. The samples collected for dissolved metal analyses did not contain any acid preservative and were analyzed identically to the raw samples. The total metal samples were taken by first shaking and the raw unfiltered sample, decanting an aliquot, and digesting the aliquot in pure grade nitric acid. The resulting solutions were then analyzed similarly to the raw samples. All raw, total, and dissolved metals analyses were conducted by CanTest Ltd., Vancouver, B.C. Additional inorganic analyses in the CTM 12 and 13 surveys were conducted by AmTest Inc., Redmond, WA except for the ferrous iron and sulfide from CTM 12 which were analyzed by Laucks Testing Laboratories, Seattle, WA.

Organics analyses consisted of volatiles (method 624), semivolatiles (method 625), and chlorinated pesticide and PCB analyses (method 608). The pesticide/PCB analysis were run using GC-ECD on the semivolatile extracts following clean-up in order to achieve lower detection limits.

The series of tables in this section (Table C-4) show the metal results from each well or station. These tables were used to screen the data for values above the performance criteria. The performance criteria were established as either the 1985 EPA chronic marine water quality criteria, or ten times background seawater concentration for contaminants without established EPA criteria. The following table (Table C-3) lists the performance criteria used in screening the data. All screening values are in mg/L with those established by EPA chronic water quality criteria indicated as "EPA". All other values are ten times the average concentration of the seawater stations 14, 15, and 16. A review of the organic results showed only one valid result above detection in well 4A for bis(2-ethylhexyl)phthalate which occurred during CTM 4. Therefore the organic data were not screened for performance criteria, however the discussion notes data of potential interest for the area wells and stations.

Table C-3
Metal Screening Criteria (mg/L)

<u>Metal</u>	<u>Screening Criteria</u>	<u>Metal</u>	<u>Screening Criteria</u>
Al	1.06	Li	2.60
Sb	0.01	Mn	0.07
As	0.036 (EPA)	Hg	0.000025 (EPA)
Ba	0.07	Mo	0.40
Be	0.03	Ni	0.0071 (EPA)
Bi	5.00	P	18.54
B	33.00	Se	0.01
Cd	0.0093 (EPA)	Si	42.92
Cr	0.050 (EPA)	Ag	0.01
Co	0.20	Sr	56.04
Cu	0.03	Sn	0.30
Fe	0.87	Ti	0.06
Pb	0.01	Tl	0.01
V	0.37	Zn	0.058 (EPA)

Results above the screening criteria for wells 2, 3, 4A, 4B, and 4C were tagged for further statistical analysis. These wells are located within the south berm which is adjacent to slip between piers 90 and 91. The berm face of the south berm is the point of compliance for the performance criteria. The five wells within the south berm are to be used to test the performance of the containment system relative to the performance criteria through a statistical analysis.

The following discussion gives a brief description of the monitoring results. This discussion is organized by the logical grouping of wells and stations occurring in similar hydraulic and geochemical environments. The qualitative descriptions of concentrations or levels is related to values above the screening levels discussed above.

South Berm Wells

Wells 2, 3, and 4 are located along the center line of the south berm with wells 4A, 4B and 4C clustered in the center of the berm. Wells 2 and 4A are the shallowest, wells 3 and 4B at intermediate depth, and well 4C the deepest. Briefly reviewing the metals data reveals that barium was consistently above ten times seawater background for the south berm wells. Manganese and nickel were also often above ten times background. Well 4C had higher values of manganese and nickel than the other south berm wells with well 3 following a distant second to 4C for these two metals. Well 4A had generally higher zinc levels. There were no significant consistent trends in over time from these wells, although barium is seen to decrease somewhat in well 4A. There was one apparently anomalous high mercury value in well 4A during CTM 3.

Dredged Material Fill Wells

Wells 5B and 5C were completed within the fill and are part of the three well cluster located near the center of the fill, with well 5C being deeper than well 5B. These wells showed higher levels for barium, iron, and manganese. Phosphorus is also somewhat elevated as are titanium and aluminum for well 5C in the latest survey. Iron, phosphorus, strontium, calcium and barium may be increasing in well 5B, while barium, strontium, calcium and manganese and titanium may be increasing in well 5C.

North Berm Wells

The north berm is situated adjacent to the freshwater pond created between piers 90 and 91 by the berm. Wells 7A, 7B, and 7C are clustered near the center of the berm with 7A being the shallowest and 7C the deepest well. All of the wells showed some elevated levels of barium, manganese and nickel. Well 7C has the highest relative values for manganese and nickel, while well 7A was relatively higher in iron, titanium, aluminum and silicon. Nickel concentrations appear to be decreasing over time in wells 7C and 7B with manganese also decreasing in well 7C. Strontium and calcium levels are decreasing in wells 7B and 7C over time suggesting that the water within the wells is becoming fresher.

Structural Cover Wells

Well 5A is located near the center of the facility and was completed in the cover material placed as a cap on top of the fill. Well 6 is located near the south berm and was completed in a mixture of mainly cover material with some fill toward the bottom of the well. Well 5A stands out among all other wells with its elevated levels of many trace metals including copper, chromium, lead, mercury, nickel and zinc. Well 5A is also elevated in the crustal rock-forming elements aluminum, titanium and silicon as well as the more commonly occurring metals iron, manganese and barium. The elevated metals levels in well W-5A has been shown to be the result of *in situ* release into suspension of metal-rich fine particulate cap material under reducing pore water conditions within the cap (see Appendix F). Well 6 stands out for its relatively high levels of manganese and its occasional anomalously high

level for copper and zinc. However, concentrations have peaked during 1988 and have been significantly decreasing through 1991 which is related to the flushing of the cap pore water (see Appendix F).

Background Seawater Stations

Station 14 is located next to the south berm, station 15 about one quarter of the way out into the Smith Cove Waterway between piers 90 and 91, and station 16 is at the end of the waterway. These three stations represent the background seawater stations. The results are unremarkable except for the anomalous mercury concentration during CTM 3 at station 14. This is the same survey which showed an anomalous mercury result at well 4A and could be related to contamination at these low sub-ppb levels.

Other Wells and Stations

Well 9 is located just west of the fill and was completed in pier 91. It was sampled twice during CTM 2 and CTM 11. Only the CTM 2 survey is shown because the CTM 11 data were excluded from the analysis, and this well was not resampled during CTM 12. The results show slightly elevated levels of copper, chromium and arsenic.

Well 10 is located north of the facility behind the timber bulkhead at the head of the old 90/91 slip and south of the containment wall of the Burlington Environmental/ Chempro tank farm and transfer facility just north of the Magnolia viaduct and south of. The results from this well showed elevated levels of BETX, LHPAHs, chlorinated hydrocarbons, phenols, and phthalates.

Station 11s samples were collected from the surface of the pond adjacent to the north berm. The results show elevated levels of arsenic and mercury, and slightly elevated nickel levels. The arsenic levels are consistently higher than any other well or station in the survey. The relatively high mercury concentration of 0.0005 mg/L during CTM 4 stands out as the highest value recorded. Calcium, strontium and barium concentrations are all apparently decreasing with time suggesting that the pond is becoming fresher. The same organic contaminants with the exception of chlorinated hydrocarbons that were found in well W-10 were found during CTM 2 and CTM 4 at station 11s except at generally much lower concentrations. These compounds were not measured during the later surveys (CTM 6 and CTM 11).

APPENDIX D - Revised Hydraulic and Transport Model, Terminal 91 Short Fill, Seattle, Washington

This report describes the revision of the hydraulic and transport model used to predict the performance of the berm-fill system over the next 100 years. The model (described in Appendix A.1, above) was revised using as-built dimensions and measured hydraulic parameters (described in Appendix A.2) along with updated values for chemical transport parameters based on a new literature search. The revisions included: calibration of the flow model to simulate the hydraulic response of the system during a two-day intensive measurement period, calibration of the transport model to simulate concentrations measured over time at various monitoring wells, and rerunning the 100-year simulation to quantify concentrations and percentages lost from the contaminated fill of various constituents measured in the fill.

Important information in the report includes:

- The original model was reviewed and revised using new data from the as-built facility (pp 1-6).
- The new hydraulic data indicate that the facility has generally higher hydraulic conductivity and similar storativity to those estimated for the original model (pp 7-9).
- The volume of the contaminated dredge material placed in the facility (about 81,000 m³) is approximately half that originally planned. The concentrations of various contaminants in the fill is 1/2 to less than 1/100 of those originally estimated (pp 9-10).
- The model was updated to include metals and organic compounds in addition to those included in the original model. New equilibrium exchange coefficients were derived from the literature for these and some of the original constituents. (pp 11-14).
- A dispersion coefficient ranging from 10 m²/day or more was used in the revised model based on the results of the updated literature review (p 14).
- The revised hydraulic model used boundary conditions represented by a pond at 8.5 feet mllw (mean low low water) along the north berm and a variety of tidal levels along the south berm. The model was then calibrated to generate water level hydrographs similar to those measured during the period July 28-29, 1988 (pp 15-17).
- The calibrated model was used to generate mean tidal velocities as input to the transport model (pp 17-18). These velocities were about two times higher than those generated by the original model.

- The transport model was calibrated using data from several sampling periods. These data were generally replicated by the model for the three main points of observation: well W-6, W-4B and at the south berm face (pp 19-22). The model was validated by generating concentration graphs for different constituents not used in the calibration process (pp 21-22).
- The combined hydraulic-transport model generated estimates for berm-face concentration and percentage leached over a 100-year period (pp 23-26). These concentrations are less than those previously estimated in part because the measured concentrations in the fill are less than those previously estimated (pp 27-30).
- Compared to the original model, the revised model predicts greater percentages of contaminants leached over time. The greater percentage resulted from: higher flow rates, greater dispersivities, and a smaller volume of contaminated fill used in the construction of T-91.

APPENDIX E - Chronic Bioassay Results

This appendix presents the results of a chronic bioassay conducted on water samples from the Terminal 91 Short-Fill and the surrounding waters. The echinoderm sperm cell bioassay was considered the most appropriate test. The purpose of the bioassay was to determine if there was any relationship between chronic toxicity and the short-fill.

Four liter water samples were collected from well 5B within the fill and from station 14 next to the south berm at low and high tide during CTM 10. An additional sample was collected from station 16 at the end of Smith Cove Waterway. These water samples were used to conduct an echinoderm sperm cell bioassay test performed by EVS Laboratories in August, 1990.

The results of the accompanying report are given in Table E-1 below. The test organisms (the Sand Dollar, *Dendraster excentricus*) were exposed to nine concentrations of sample ranging from 0.1% to 100% by volume for 30 minutes. The endpoint of the test is fertilization of the Sand Dollar eggs by the sperm.

Table E-1
Summary of Echinoderm Sperm Cell Bioassay

<u>Sample</u>	<u>EC50</u>	<u>NOEC</u>	<u>LOEC</u>
Well 5B	> 100%	25%	50%
Sta. 14 Low	> 100%	12.5%	25%
Sta. 14 High	> 100%	25%	50%
Sta. 16	> 100%	50%	75%

The abbreviations EC50, NOEC and LOEC mean: effective concentration (50%), no observed effect concentration, and lowest observed effect concentration. The EC50 of > 100% means that statistically 50% of the organisms would have some observable non-lethal adverse effect at 100% and greater concentration of the sample. A NOEC of 25% is the highest concentration at which no statistically significant observable non-lethal effects would be seen, and a LOEC of 50% is the lowest concentration which causes some statistically significant non-lethal effect to occur.

All samples exhibited some statistically significant chronic effects. The sample from station 16 at the mouth of Smith Cove Waterway showed the least effect and station 14 at low tide showed the most. The water from within the fill (Well 5B) showed similar chronic effects as did the seawater adjacent to the south berm at high tide.

The first hypothesis that reducing organic-rich pore water from the fill has released dissolved metals from the reduction of oxidized metal oxyhydroxide coatings on the sands and gravels of the cap material is also not supported by the data. The data indicate that the cap has remained fresh and that saltwater from the fill has ever reached the cap. Consequently, this evidence rules out any direct long-term influence of the dredged material fill on the cap chemistry for the Terminal 91 Short Fill.

In addition, any adverse impacts of the suspended material from the freshwater cap on ambient saltwater quality would be considered highly unlikely based on the data and evidence gathered in this study. Based on the evidence presented in this report, the high suspended metals concentrations only occur in freshwater under reducing conditions. As the freshwater from the cap reaches the outer berm, it mixes with oxygenated seawater. This will cause the ferrous iron in the cap pore water to be oxidized and ferric hydroxides to precipitate, along with much of the other colloidal material including the metals and organics. In addition, this process is compounded by the colloidal inorganic material will be de-stabilized by saline aggregation which will also cause the suspended material to precipitate. Therefore we can expect that the berm will act as an efficient trap for the suspended particulate material from the cap.